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ABSTRACT

The National Science Foundation (NSF), through its Division of Undergraduate Education, is undertaking a major effort to significantly improve the mathematics and science education of prospective elementary and secondary school teachers. NSF had two major goals in organizing this workshop. The first goal was for the Foundation to learn from active scientists who have been involved in developing exciting and interesting courses, and from experts in elementary and secondary school education, about the needs of prospective teachers and about promising approaches for undergraduate science education that are particularly appropriate for prospective teachers. The second major goal of the Workshop was to provide information, encouragement, and inspiration to faculty from the scientific disciplines as they seriously consider their role in the preparation of prospective teachers. The first portion of the proceedings contains group presentations on the following themes: innovative instruction, valuing diversity in the educational process, research on teaching and learning, and assessment and evaluation. This portion of the proceedings also addresses the strategies that faculty in the scientific disciplines can employ that would be particularly appropriate for prospective elementary, middle, and secondary school teachers. The second portion of the proceedings contains presentations on the role of faculty in the undergraduate education of science and mathematics teachers from the following disciplines: chemistry, engineering and computer science, geosciences, interdisciplinary, life sciences, mathematical sciences, and physics. The proceedings of each disciplinary panel contain reports from thematic group representatives. Supplementary materials include a listing of participants, and information on NSF support for preparation of teaches. (LZ)

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Proceedings of the National Science Foundation Workshop on

The Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers

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Proceedings of the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers

National Science Foundation
August 1993

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DIRECTORATE FOR EDUCATION
AND HUMAN RESOURCES

Division of Undergraduate Education

July 19, 1993

Dr. Luther S. Williams
Assistant Director for
Education and Human Resources
National Science Foundation
Washington, DC 20550

Dear Luther:

I am pleased to submit to you the Proceedings of the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers.

Held in November 1992, the Workshop and the resulting Proceedings form an important part of the Foundation's efforts to fully engage faculty from the scientific disciplines, in collaboration with faculty from schools of education, in the preparation of prospective elementary and secondary school teachers. The workshop brought together scientists and educators who have been particularly successful in providing the type of scientific experiences that should be available for all prospective teachers. In addition, the workshop participants considered from the disciplinary, and interdisciplinary, perspective what the role of these faculty should be in preparing future teachers.

As you know, this workshop and report are part of a continuing series sponsored by the Division of Undergraduate Education (DUE) to highlight national issues in undergraduate science education.

The Workshop Proceedings will serve as a valuable tool for those promoting change within their institutions, for individuals submitting proposals to the National Science Foundation, and for the Foundation as it manages its efforts to improve the preparation of prospective teachers.

Sincerely,

Robert F. Watson
Division Director

Foreword

William E. Haver, National Science Foundation and Virginia Commonwealth University

Herbert Levitan, National Science Foundation and the University of Maryland

The National Science Foundation, through its Division of Undergraduate Education, is undertaking a major effort to significantly improve the mathematics and science education of prospective elementary and secondary school teachers. A basic premise of the Foundation's efforts in this regard is that the mathematics and science that prospective teachers learn as part of their undergraduate education, and the manner in which they acquire this knowledge, has a critical influence on the quality of their teaching. Because of the great importance of this undergraduate experience it is clear that faculty from the science and mathematics disciplines must play a major role in the preparation of prospective teachers.

The Foundation had two major goals in organizing the "Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers." The first goal was for the Foundation to learn from active scientists who have been involved in developing exciting and interesting courses, and from experts in elementary and secondary school education, about the needs of prospective teachers and about promising approaches for undergraduate science education that are particularly appropriate for prospective teachers.

The second major goal of the Workshop was to provide information, encouragement, and inspiration to faculty from the scientific disciplines as they seriously consider their role in the preparation of prospective teachers. The Proceedings can serve as a useful resource as faculty plan curriculum development activities, with or without potential support from the Foundation.

The first portion of the Proceedings addresses several themes that NSF and the participants considered to be of particular importance to prospective teachers but that would also serve to improve learning by all students. The themes, which reflect the activity of panels and segments of the Proceedings are: innovative instruction, the diversity among students, research on teaching and learning, and assessment and evaluation. This portion of the Proceedings also addresses the strategies that faculty in the scientific disciplines can employ that would be particularly appropriate for prospective elementary, middle, and secondary school teachers.

Elaboration of Major Themes of Workshop

Instructional Innovation: The most common mode of undergraduate instruction is the lecture. Most disciplinary faculty are not involved in developing and experimenting with modes of instruction that acknowledge that students may learn in a variety of ways or that take advantage of newly developed technologies. Workshop participants contributing to this panel examined

a variety of innovative approaches that are alternatives to teaching through lecture. They were charged with considering questions such as: How can faculty be encouraged to exhibit comfortably, and in the classroom as role models, their own dual mixture of scientific training, instinct, and ignorance? How can instructional curricula that purport to "tell it like it is" also encourage a sense of discovery, uncertainty, paradox, and mystery? (That is, can disciplinary faculty be encouraged to take risks and explore innovative pedagogy that could enhance the learning of subject matter, while demonstrating to prospective teachers the potential dynamic nature of teaching and pedagogy?) How can we encourage instructors to discuss, with their students, their strategies for teaching various concepts or techniques? Examples include collaborative and cooperative learning, methods of engaging students in large classes, the uses of writing by students, peer teaching, the appropriate use of instructional technology, and other means of promoting active, experiential learning.

Diversity: Students in any course have diverse backgrounds and experiences that profoundly influence the way they learn. By acknowledging this diversity and learning how to utilize it, faculty can empower students to pursue their career goals in ways that call upon the students' strengths. Workshop participants contributing to this panel shared their perspectives on how faculty in the scientific disciplines can enhance student learning by appreciating diversity as a resource rather than a diversion. Such perspectives can serve future teachers as models for use in classroom teaching at any level. The participants were charged to consider: How can the different aspirations of students in a class, such as those intending to major in the discipline, those majoring in other science and mathematics disciplines, non-scientists, as well as those aspiring to careers in teaching, be turned into an opportunity for a positive learning experience? What is the impact of: different learning, studying, and communication styles; different types of personality in the process of identifying problems and suggesting creative solutions; varying racial, ethnic, cultural, and class backgrounds; and differences in experience, age, gender, and physical abilities? Can these differences be acknowledged and utilized in classes with very large numbers of students?

Research on Learning: Although research exists on how students learn science and mathematics, faculty in the disciplines are for the most part unaware of this research and its relevance and potential to inform their own teaching of undergraduates. Moreover, faculty in the scientific disciplines, in general, do not participate in such research or engage their students in thinking about how people learn. Faculty often describe current basic research hoping to interest students to consider careers in their discipline. Similarly, faculty who share with students an interest in exploring how students could learn better might give students an appreciation of the dynamic nature of teaching, encourage students to pursue teaching as a profession, and contribute to the development of new ways of facilitating learning by others. The objectives of this panel were to share some key results of research on how students learn science and mathematics, consider the implications for teaching undergraduates, provide a basis for faculty in the scientific disciplines to acknowledge such research as a legitimate scholarly activity, and consider ways that faculty can participate in such research. Workshop participants contributing to this panel were charged to consider: How can undergraduate faculty in the scientific disciplines be made aware of research on learning? How can faculty in the scientific disciplines incorporate such research into their courses both to improve learning by all students with diverse career objectives, as well as to accommodate the interests of future teachers? How might prospective teachers be engaged in research on teaching and learning, in a way and for the same reasons, that research experiences for undergraduates in the scientific disciplines is considered valuable and desirable experience both for enhancing learning of the subject and to inform career decisions?

Assessment: Assessment of student learning, which is often viewed as the sole prerogative

and responsibility of the faculty, is also an important skill for future teachers to master. Yet, because the process of deciding what to assess and how to assess requires a broad and deep understanding of the subject matter, engaging all students in the process could serve everyone's objectives. Workshop participants contributing to this panel were charged to consider: What different types of assessment devices and mechanisms are available? How can assessment be structured so that the assessment experience becomes a learning experience as well? How can assessments be structured to enhance learning, more accurately reflect a student's understanding, and lower students' anxiety? How can preparation of assessment devices by students be used to enhance the learning experience?

It will not be an easy task to create learning experiences for the majority of our Nation's prospective teachers that are influenced by these ideas. We believe that these Proceedings, which reflect the thinking of leading scientists and educators on these issues, will provide a good point of reference for future work in these areas.

The actual manifestation of ideas such as these occur with the development, implementation, and teaching of particular science, engineering, and mathematics courses. Often, and appropriately, these courses are focused in a particular discipline; sometimes they are interdisciplinary in nature. Therefore, the second part of the Workshop, and the Proceedings, focused on implementation within interdisciplinary courses and within courses in the following disciplines: chemistry; engineering/computer science; geosciences; life sciences; mathematical sciences; and physics.

The Proceedings describe the reaction of the participants in each of the interdisciplinary and disciplinary groupings to the major themes considered in the first portion of the workshop, and to the particular needs of individuals preparing to teach at different levels. While the workshop participants did not attempt to prescribe the exact experiences that prospective teachers should have, they did agree on the general tenor of the desired experiences; in particular, they shared the view that undergraduate courses taken by all students, and future teachers in particular, must actively engage students much more than is the case in common practice.

What follows is truly a proceedings of the Workshop; it does not represent final thinking on the part of the participants nor the Foundation. Neither the participants nor the NSF are under the illusion that there is a clear blueprint for the ideal program to prepare prospective teachers. By the same token, there is no clear strategy to ensure that faculty from the disciplines will engage in this activity to the extent required to significantly improve the quality of future teachers.

What did occur during the workshop were lively and exciting discussions and demonstrations about possible roles of faculty from the scientific disciplines in this enterprise. We hope these Proceedings convey this excitement and these possibilities, and prove to be a valuable resource for engineers, mathematicians, and scientists as they work to strengthen and renew undergraduate science education for prospective teachers and for all students.

The work leading up to the actual Workshop, the activities of the Workshop, and the Proceedings have been very valuable for the Division of Undergraduate Education in the development of Program Announcements, in the review of proposals, and in the overall management of its programs.

The program of the Foundation that provides support for collaborative efforts between disciplinary faculty and faculty from schools of education, and the programs that provide direct support for improving science courses, curriculum, and laboratories are described in the Epilogue to the Proceedings.

Keynote Address: Role of Faculty in the Disciplines in Undergraduate Education of Future Teachers

William E. Kirwan, President, University of Maryland at College Park

Thank you very much for the opportunity to speak at this very important National Science Foundation workshop. The Foundation is to be commended for the priority it has given to reform in science and mathematics education. We all know the crucial role that NSF has played in enabling the U.S. to develop the strongest scientific research capability in the world. With the Foundation's support, we must work to achieve a similar status in science and mathematics education.

The participants in this workshop also are to be commended. The changes that need to take place in classrooms across America can occur only if faculty like you become deeply involved in the reform effort.

We must not underestimate the magnitude of the challenge facing us. The word crisis is not too strong to use in describing the alarming condition of science and mathematics education from kindergarten through college. Let me cite just a few examples to illustrate this point.

A recent nationwide College Board examination asked 17-year-olds to convert 9 parts in 100 to a percentage. As incredible as it may seem, 47% of the participants could *not* solve this problem correctly.

Several equally disturbing facts were uncovered in a study comparing the performance of students in 120 classrooms in three cities: Taipei, Taiwan; Sendai, Japan; and Minneapolis, Minnesota. The study, conducted by Professor James Stigler of the University of Chicago and Professor Harold Stevenson of the University of Michigan, involved first- and fifth-grade classes from representative schools in these three cities. Among the 100 first graders in the three locations who received the lowest scores, 58 were Americans. That's bad enough. But, of the 100 lowest scoring fifth graders, 67 were American. At the other end of the scale—only 15 Americans were among the top 100 scorers in the first grade and—shockingly—only 1 American was among the top 100 scorers in the fifth grade.

These and other similar studies are disturbing not just because they injure our national pride. More substantively, they portend a national calamity in terms of our country's status, power, and well-being as the world moves toward an ever more technologically dependent and internationally competitive economy.

Surely, the superpowers of the 21st century will be those nations that can deliver to their citizens—among other things—abundant and low-cost energy, a technology-driven economy, high-quality telecommunications, affordable health care, and an unpolluted environment. The intellectual effort and the technological expertise to address any one of these needs is daunting. Overall success will require a highly educated and motivated workforce, something we will *not* have unless radical changes occur in our educational system.

The educational analyst Paul Copperman summed up our situation well. He said, "Each generation of Americans has outstripped its parents in education, in literacy,and in economic attainment. For the first time in the history of our country, the educational skills of one generation will not surpass, will not equal, will not even approach, those of their parents."

The blame for the decline in school performance by American students—as measured by standardized tests—is placed by some on underachieving minority students thought to be pulling down national test averages. In fact, just the opposite is true. For example, the average SAT scores of blacks, although still below those of whites, rose almost 50 points in the decade of the 1980's. The national decline in SAT scores is almost entirely attributable to the diminished performance of the students in the top quartile. Indeed, since 1970 there has been a 40% decline in the percentage of students with a combined score of over 1200 on the SAT exam.

This suggests that the poor school performance by American youth has two distinct components: underachievement by the economic underclass—largely minority and inner-city—and underachievement by the more affluent—primarily white and suburban. We must recognize that the root causes of these two problems are different; that their solution will require overlapping but distinct strategies; and that *both* problems must be addressed if the Nation is to have any hope of sustaining—into the 21st century—its current position of economic supremacy.

Why has it been so difficult for the Nation to effect meaningful reform in mathematics and science education, particularly since the need is so great and the case is so clear? The reasons are varied. They include the fact that the consequences of inaction are in the future. As a people, we are better at addressing immediate issues than long-term goals. Investment in the future is not one of our strengths. This is true of our businesses, with our personal finances, and in the development of our workforce for the 21st century. Unfortunately, by the time our educational deficiencies become an immediate problem, it will be too late to avoid the consequences of present inaction.

There is also the problem that our educational system is highly complex. Each level depends upon and affects the levels immediately above and below. Where does one start the process of reform? At the preschool level? If so, it could take the better part of two decades for reforms to work their way through the system. Do we start at the high school level? How would that be possible if the students entering high school arrive from middle school with present deficiencies? Should we begin at the college level? It is, after all, the colleges and universities that train teachers for the K-12 classroom. Do we start at all levels simultaneously? Such an approach is almost too complex and too expensive to contemplate.

I believe a strong case can be made that the university level is the best place to begin the reform effort. Not only do the universities train the teachers for the K-12 classrooms, it is the universities that provide the final phase of education for the Nation's technological workforce.

Further, I believe that our colleges and universities share more of the blame for the educational problems our Nation faces than has heretofore been attributed to them. We in the university community have been quick to point to the educational deficiencies of entering freshmen, slow to embrace meaningful partnerships with the K-12 sector, and recalcitrant in examining the quality of our teacher preparation programs.

However, I do not think it is possible to talk about reform of teacher preparation programs without speaking more broadly about reform in collegiate level science and mathematics education. If future teachers are to take more discipline-based courses—as I think they must—then their knowledge of content areas will reflect the quality of undergraduate education offered to all students.

I would like to suggest four actions that I believe are necessary if we are to address deficiencies in science and mathematics education,

deficiencies that include the preparation of teachers for the K–12 setting.

1. *Expand the faculty reward structure.* This suggestion is directed primarily at our Nation's research universities. These universities are especially vital in implementing reform because they not only teach vast numbers of undergraduates, they also tend to set the norms and standards for all of higher education.

   At too many research institutions, too little encouragement exists for faculty to engage themselves in issues of teaching and learning. Actually, the situation is worse. Often a stigma is associated with those who do get involved. I want to make clear that such attitudes are not restricted to the faculty. Everyone from trustees, to presidents, provosts, deans, and chairs bear responsibility for the relatively low status accorded teaching responsibilities at research universities.

   The consequences of an almost exclusive attention to research in the faculty reward structure are not surprising. Too many entry-level courses are taught in large lectures; students complain of not being able to see faculty even during office hours; the undergraduate curriculum is static—in mathematics, for example, little has changed in the nature of the lower division courses over the past 50 years; the meaningful interaction of the computer into the curriculum has not yet occurred; and too few discipline-based faculty are involved in training K–12 teachers or in outreach to the schools.

   The single most important thing that can be done to improve mathematics and science education in our Nation's schools, colleges, and universities is to make faculty contributions to teaching and learning comparable in importance to contributions in research.

   I say "comparable" because we must not create new problems in solving old ones. America's research universities are our primary source of ideas for the future advance of our society. The difficult task for universities is to find a way of elevating the importance of teaching and learning without diminishing the opportunities for important research. This will require wise and determined administrative leadership, for no one should underestimate the difficulties in changing the nature of research universities to accommodate appropriate rewards for work in the curriculum and for excellence in teaching.

2. *Create a more active learning environment in science and mathematics courses.* A recent study, supported by the Sloan Foundation, brings into focus one of the major problems with present-day science and mathematics education. The study was spawned by some troubling data in an NSF report. According to this report, approximately 60% of freshmen who enter college as science, mathematics, or engineering students either switch to nontechnical majors or drop out of school. And only half of these students leave science, math, and engineering because they believe the work is too difficult. They leave in large numbers because they have become disenchanted with their course work and find subjects in the social sciences and humanities more stimulating.

   These findings are based on research done by Sheila Tobias and, independently, by Nancy Hewitt and Elaine Seymour. These researchers visited several campuses, sought out, and interviewed students who had left the sciences for other majors.

   A common theme in the students' responses was that they had come to college excited by the possibility of a career in the sciences or engineering but quickly became disillusioned. They believed they were passive participants in the educational process. They did not have a sense of "personal discovery of knowledge," a sense they got from courses in nonscientific fields. These studies also showed that many students who persist in science and engineering do so despite, not because of, their lower division courses.

Again, because it is my discipline and I know it well, I turn to mathematics for an example. Traditionally, a "good" mathematics lecture has been thought to be one where a professor comes into the classroom and talks at—not to—the students, is uninterrupted by questions for 50 minutes, and provides a completely logical explanation of the most general version of a complicated theorem. Explanations as to what motivated the theorem, how it evolved over time, its significance in a broader context, rarely occur. Whether or not this was *ever* the appropriate way to teach mathematics, it is most definitely not working now.

In summary, we must overhaul the way we teach mathematics and science. We must learn how to engage the students—including future K-12 teachers—as active participants in the learning process. This will not be easy, but promising pilot efforts exist at colleges and universities across the country.

3. *Provide better funding for lower division instruction in mathematics and science.* The standard mathematics and science instruction method at most large and many small universities is the lecture/recitation format.

   In disciplines like writing and foreign language, however, where drill not unlike that required in mathematics and science courses is essential, university administrators have accepted the notion that large lectures are not appropriate. These courses are almost always taught in small sections with substantial student faculty interaction. Given the crisis we face in producing a scientifically literate population, we need to rethink the large lecture method. The cost of changing to courses taught in section sizes of 20 to 30 students is substantial. But these costs can be mitigated by asking faculty less involved in meaningful research to assume more classroom responsibilities. It is probably also the case that some courses and some instructors are suitable for the large lecture environment.

4. *Establish closer ties with the K-12 sector.* The problems we face in reforming math and science education are so complex, interdependent, and interwoven, they can only be addressed through broadly based collaboration between universities and the schools. We must stop finger pointing and begin bridge building. Higher education needs to listen to the K-12 and vice versa. We need to expand the number of statewide coalitions and summer workshops for science and mathematics teachers, we need to revamp teacher preparation programs, we need to develop faculty/teacher exchange programs between schools and universities, and we need on-campus experiences for students of all ages. But this brings my suggestions full circle. The kind of collaboration I am describing will come to pass on the scale necessary only if universities adopt my first recommendation—an expanded reward structure.

I hope you find these comments useful. The most important thing occurring at this workshop, however, is your presence and involvement in this program. I extend my best wishes to you as you continue to grapple with one of the most difficult but important problems facing our Nation—the development of meaningful reform to elevate the quality of science and mathematics education in our Nation's schools. I and others look forward to studying the results of your deliberations.

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Keynote Address: Bridges Within Academe

Robert W. Parry, Distinguished Professor of Chemistry, University of Utah

Today all of us have heard of the importance of developing the concept of cooperation between industry and the academic world. The citizens have made it very clear that "science for science's sake" is fine as long as it is coupled with an economic pay-off for the citizen. The message is coming loud and clear from the people to Congress, from Congress to government science and business leaders, and from all to scientists on the line in both the academic and business worlds. Such cooperation has many benefits including increased understanding of the science enterprise in two very different settings and an increase in our ability to incorporate the benefits of science into our economic life.

Less publicized today is an equally important cooperative effort. At this workshop, we are interested in building bridges between the science-based faculties and the education-based faculties who sometimes attack each other while they are attacking the everchallenging problems of education in America. In my judgment, building such bridges is one of our more important efforts and it takes on increased urgency as severe budgetary constraints bedevil political leaders who are caught between national concerns about both budget deficits and educational shortcomings. In this intellectual climate, it is mandatory that all of us in education unite in our efforts to improve the process of educating and training our young people.

Interestingly enough, I can remember a situation after WW II when scientists were shocked by the scientific training of politicians. I am sure the name James B. Conant is familiar to at least a few of you. Conant was a chemistry professor at Harvard. He was a world-recognized scientist, a great teacher (who wrote an organic chemistry book), and the president of Harvard University in the 1930's and 1940's. During WW II, he was called to Washington to work with Vannevar Bush in the mobilization of the Nation's scientific defense efforts. In this capacity, he had to carry to Congress requests and recommendations for the utilization of the country's scientific talents in the prosecution of the War. He had one experience that bothered him to no end.

He went before a Congressional committee to ask for $50,000 for a *feasibility study* for a proximity fuse. The amount of money was not large, even in those days, but as is customary in appropriation matters, the smaller the budget the more intense is the questioning.

The first question set the tone. "Professor, what do you mean by a proximity fuse?" Conant's reply was factual and honest. He said, "A proximity fuse is a device which when placed in a antiaircraft shell would trigger a detonation if the shell approached an object in the sky. This would then scatter shrapnel and knock hostile aircraft out of the sky. The idea seems attractive from a military standpoint, but we do *NOT* know whether or not we can ever make a proximity fuse. The money we are requesting is for a *feasibility study.*"

The next question from the committee was a zinger. "Professor, how long will it take you to get this proximity fuse into the field? If we gave you $5,000,000 could you have it in operation in 6 months?" Conant was completely surprised. Clearly his earlier comments had gone past the man. He held his temper. "Congressman, we don't know whether or not we can even do this. The money is for a *feasibility study*." With a smile on his face the congressman came back with, "Professor, $10,000,000 and a year?"

Conant was so distressed at the lack of understanding in Congress about matters relating to the procedures and processes of science, that when he returned to Harvard in 1947 he convened a meeting at Harvard of some 50 of the young professors of science and science education from around the U.S. and told us, in no uncertain terms, that our job was to see that at least our leaders knew something about scientific procedures. He passed the torch. We dropped it. We failed in his mandate, but I believe we have made some progress--thanks in large measure to the efforts of the National Science Foundation, the military research offices, the National Institutes of Health, and other science-related agencies.

The job ahead is still an important collaborative effort. How important is underscored by an early experience (about 1960) that I had with a teacher in the Ann Arbor public schools. Her name was Kathleen McClure. In the late fifties and early sixties, scientists were riding high; we firmly believed that the very difficult will take a few days and the impossible will take a few months. Don't worry! A number of the leaders in the education schools were equally cocky. A professor in an Illinois college of education made national headlines and stirred up lots of criticism by the assertion that he could teach anything because he knew how to teach. Never the twain shall meet!

Kathleen McClure put the whole thing into focus for me. She taught kindergarten in the Ann Arbor schools, and one of my sons was in her class. She was way ahead of her time in the belief that kindergarten kids should know something about science. One day she came into my lab and asked me what help I could give her in identifying a science problem for her kids. My mind at the time was a long way from kindergarten science projects, and I admitted that I was stumped. At that particular moment, I had weighed out some blue $CoCl_2$ crystals, and while she was watching, I dumped them into water to make a solution which was a lovely red. Her response was instantaneous, she said, "What did you do? I can use that." I told her what had happened, gave her some blue $CoCl_2$, told her about drying the red salt to make it blue, then she left. At best I thought she would be able to do a 5-minute science demonstration which would wash over the kids and be gone like a medium-sized wave. I was wrong.

The next day she was back in my office with "Mr. Buttonhead" and one of the most clever science projects for 5-year-old's that I have ever seen. Mr. Buttonhead was a puppet. His head was a large wooden button about 2 inches in diameter, and it was covered with cloth which had been soaked in the $CoCl_2$ solution. She dried the buttonhead until it was blue. His face was painted on. A stick into the bottom of the button gave a handle, and Mr. Buttonhead's coat was white cloth which covered the handle by which students held him. He had on a jaunty hat. She made one of these for each of the 30 kids in her class. Their assignment was, "What will make Mr. Buttonhead blush?" The kids could put him in different places in the classroom to see if he would blush.

One little guy who was sort of "spacey" forgot and left his Mr. Buttonhead on the table near a faucet where it got splashed with a few drops of water. He came over to her all excited and said his Mr. Buttonhead was blushing. She said "No, his Mr. Buttonhead seemed to have the measles." She told him to think it over. He went back, took a wet rag and touched Mr. Buttonhead's cheeks. *Voilà*, he blushed! She praised the boy, took his Mr. Buttonhead and asked him not to tell the others for a few days. He was bursting with pride and a desire to tell the other kids, but he did as he had been asked. After several other

kids had found the key she gave the rest of the kids clues until all knew about Mr. Buttonhead. When the kids from that class were in college, they could still remember Mr. Buttonhead. Mrs. McClure was a fantastic teacher.

Our problem today is, "How do we engender that spirit of creativity in teaching which was displayed by Kathleen McClure?" She needed some scientific help, but she was the one who saw how to take a small scientific fact and convert it into a game which her students would remember for years. Unwittingly, because of Kathleen McClure's skill as a teacher, I became a part of a very successful teaching activity and I would never again forget that knowing about kids is as important to science education as is knowing about science. Cooperation can be fun and instructive to both research scientists and teachers in our schools.

In July of 1992, Ramon Lopez of the University of Maryland, a distinguished space physicist who has worked closely with local schools, published a paper through the National Academy of Science Op-Ed Service. In my judgment, he had many of the problems of education clearly in his sights. His opening comment put the problem in focus. I quote: "Millions of young Americans barely know the difference between a protein and a proton. In a world that depends on science and technology they are in trouble." He wasn't too sympathetic to his colleagues in science. He wrote: "Unfortunately, although scientists complain about science education regularly, they tend to be like most people in not getting involved in something that doesn't affect them directly." He also wrote: "Another reason scientists aren't doing more is that they come to school expecting to fix a situation that they really don't understand. Well-meaning scientists sometimes believe all educational problems would be solved if only teachers would listen to them. They fail to recognize that knowing something about chemistry or biology does *NOT* make them experts in teaching young people." As I read this, visions of Kathleen McClure and a young chemistry professor at a respected major university filled my mind.

Another past experience also is pertinent here. When America was frightened by the Soviet satellite, Sputnik, which orbited the earth in 1958, tremendous interest (and criticism) of our schools erupted across the Nation. The government science programs, PSSC, BSSC, CHEM STUDY, etc., resulted from the concern of John Q. Public over our relative standing in world science. I was involved in one of the early planning meetings for CHEM STUDY, and the events of that meeting are etched into my memory. A large meeting of researchers and high school teachers was convened in California with the charge of developing a "bare-bones" high school curriculum which every student of high school chemistry must master. The document which emerged at first, represented a course which few in the room could pass, let alone teach. Ken Pitzer, a distinguished member of the faculty at Berkeley, brought us back to reality. He was the "Kathleen McClure" of CHEM STUDY in that instance.

In recent Notices of the American Mathematical Society, William P. Thurston, a Fields Medalist and internationally known researcher in topology and geometry stated, "Mathematics education is in an unacceptable state. Despite much popular attention to this fact, real change is slow." The same may be said of science education, but we must keep trying. No one has the answer, but together we will make progress.

Having said all of the foregoing, I find it a bit presumptive to offer detailed advice in an area where there are as many correct answers as there are students and many, many incorrect answers. Some students respond to one approach, some to another. Here are my views on science teaching. Take them for what they are worth. The decision varies with the reader.

(1) Concepts, structures, and processes of science and math are fine for a correlating theme, but one must not neglect necessary vocabulary and facts. Our models still can't replace experiments.
(2) As we learn more and more, "the connectedness" of knowledge is easier to see. The role of nitrogen bases in passing on genetic infor-

mation from generation to generation was never recognized by the brightest minds of the 1890's. More knowledge made correlations easier.

(3) History of science can frequently provide a connecting thread for scientific events This statement is beautifully illustrated by Gerald Holton, Professor Emeritus of Physics at Harvard, in his classic book, *Introduction to Concepts and Theories of Physical Science* (Cambridge, MA: Addison-Wesley, 1953). Professor Holton uses the historical approach to present science as it really is—human beings with all their weaknesses, distractions, and foibles jousting with nature for knowledge as the prize.

(4) Most of us are agreed in 1993 that the experimental, hands-on science is the best way to gain and hold student interest. For the most part, as Professor Thurston so clearly pointed out, change is slow. Our goal is to structure our discipline so that students are active participants. The lab is the medium. Even today, after very sizable investments, our labs don't do what we want—particularly for early courses. There are many reasons including the following:

(a) The subject matter is frequently a verification of older classical experiments.

(b) Labs are taught by teaching fellows who, in many, if not most, cases don't understand the fine points of the exercise being carried out and many don't care.

(c) Equipment and supplies are frequently old and, in some cases, not functional. Student frustration levels approach the stratosphere when old equipment and poor materials generate results which don't resemble those which are expected from information given elsewhere in the course.

(d) The labs require physical work as well as intellectual effort.

(e) Lab work is difficult to evaluate properly.

In summary, we can paraphrase Professor Thurston's comment: "Labs are in an unacceptable state. Despite much popular attention to this fact real change is slow." My own addition to this statement is, "We must work together to maintain forward progress even if it is slow." We all have skills, and no one has all the right answers. Let's keep pushing *TOGETHER*.

Workshop Themes

**W.A. Sibley, Vice President for Academic Affairs,
The University of Alabama at Birmingham, Co-Chair**

Executive Summary

The purpose of this workshop is to build a bridge between disciplinary professionals and school of education professionals which will allow this country to meet the challenges of developing and educating future teachers. Future teachers, and those who are now involved in the education process, have a number of challenges before them. There is now pressure to educate our young people to meet the economic challenges the Nation faces. We must create a meaningful culturally responsive pedagogy. Teachers must have a strong base in the disciplines they teach, which means more communication between school teachers and faculty involved in the education process at the universities. There will be a coupling of schools and colleges in new partnerships, and the future teachers must know how to enhance this bridge. The financial constraints on teachers for classroom equipment and supplies have always been great, but new teachers must be alert to these problems and involved in ways to solve them. Assessment will be a major part of the new teaching, but this must be done by viewing the needs of the students to help them reach their potential. It must not be based on simple formulas or ideas which emphasize only cost. New teachers must be able to use multimedia teaching devices effectively, deal with student diversity, and formulate new teaching methods through group programs.

Thematic Working Groups

The themes chosen for this working group cover a wide but important range of topics. It is important to understand that each of these topics has an overlap integral that includes the other areas. *Assessment and Evaluation as a Means To Enhance Learning* builds on the experiences from *Instructional Innovation, Valuing Diversity in the Educational Process, Research on Learning and Teaching Science and Mathematics,* and especially on *Experiences for Elementary and Middle School Teachers* and *Experiences for Secondary School Teachers.* If this country is to be successful in developing an even more effective K–12 system, future science and mathematics teachers will need direction and insight. This workshop can blaze a path which will be very useful to future teachers. It should reinforce their preparation for the future. One example of the interaction needed to accomplish this is that of Teacher Education Councils. It has been my privilege for the past several years to chair the Teacher Education Council at The University of Alabama at Birmingham (UAB). This council is important to UAB because it encompasses faculty from the School of Education and the Disciplinary and Professional Schools.

People working together, sharing ideas and critical thoughts are able to make much greater progress than those who do not have the oppor-

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tunity to discuss with other people who do not accept their ideas.

The opportunities for us today are myriad. There are numerous areas in which improvement or enhancement can be made. As an example, mathematics education is now involved in almost every degree program. If students are to make progress toward a degree in the university they must have an adequate mathematics background. New teachers must know how to accomplish this with the students from elementary school to high school. In many of our universities, 50 percent of the precalculus students in mathematics fail or drop out of the courses. This is an area that requires much emphasis since it is at the root of many degree programs.

With the advent of computer and multimedia teaching devices, there is a tendency to let the tube do the teaching. There is no doubt that individually paced instruction with computer and multimedia will be a great asset to the teaching process, but they must be used correctly. What is the appropriate balance between "chalk and talk" (which is still important) and computer-aided instruction? How much problem solving is really needed in a physics course as compared with providing excitement and general enlightenment?

In education as well as research, we have moved more and more toward team activities. When I was being educated as a physicist, it was not thinkable for us students to work together. Now we find that both the learning process and the research process is enhanced by the team approach. I am told now that young faculty want to work as teams and that middle school programs find that team learning is a tremendous assistance. People find more security, more fun, and, perhaps, more creativity in working together. How will this affect the teaching of future science and mathematics teachers? How will they use study teams? What techniques will be most effective with our future students? The diversity of our students has a special place in this discussion. Those of us at urban universities understand very well that there is great diversity within our student bodies. This is helpful. Those who pass through our educational programs will have to learn to deal with others from diverse backgrounds and cultures. The world continues to shrink in transportation time and communication. The advent of interactive television enables us to establish international conferences or workshops on very short notice through MCI or AT&T. This voice-activated talk back capability will play a major role in future education. It is imperative that students learn to value one another and to appreciate the diversity of the various cultures. This will make us a stronger country.

The opportunities to teach more and better mathematics and science, deal with the diversity of students, and utilize technology are great, but in order to apply these tools and techniques effectively, there must be assessment and evaluation. The assessment and evaluation process must be thorough. Baseline data that compare "apples to apples" must be available. There must be a feedback process. We must know what works and what does not work in various situations. We must be able to detect early stage changes in student attitudes and student working styles. Continuing assessment is a must.

Charge

My charge to this group is short:

1. Review, evaluate, and make recommendations that will help us educate future teachers better in these thematic areas.
2. Each person in the workshop must be familiar with the various thematic areas and contribute toward a bridging process between these areas and the disciplines. Therefore each participant should feel good about discussing both the themes and the disciplines in each group.
3. The thematic representatives must report to the disciplinary groups on their discussions.

Disciplinary Faculty and the Education of Teachers: A View from the ED School

Judith Taack Lanier, President, Michigan Partnership for New Education, Michigan State University, Co-Chair

We all recognize the traditional criticisms and stereotypes that surround university work in teacher education. Elementary teachers do not come to know the disciplinary subjects they must teach. Secondary teachers do not come to know the pedagogical knowledge they need. And neither elementary nor secondary teacher candidates get the depth of practical knowledge and skill needed for an effective first year of teaching. These legendary complaints are now topped with new allegations—charges that we neglect major changes in today's student population, new policies and practices in public schooling itself, and emerging knowledge about effective teaching and learning. There is, of course, some truth to these claims, which is why we have gathered to discuss promising remedies.

A Context of Change

Our thinking will be enhanced, however, if we are knowledgeable of the current educational scene in America—for the work of teachers is changing. While it is not yet changing dramatically or evenly throughout the Nation's schools, it *is* changing—gradually, and with growing momentum. The changes emanate from a growing set of demands for more and better student learning—demands that come from a changing technological society that needs more citizens and more workers able to think, problem-solve, create, and work flexibly with advanced knowledge and technical skills. The changing demands for higher-level learning for more students than we have reached before alter significantly the intellectual demands placed on teaching *and* teacher education. Our society has been urging these changes for some time now, but not yet with great success.

Policymakers and the education establishment have struggled seriously for over a decade to both improve and increase school learning—and to better our return on the substantial financial investment we make in education at local, state, and national levels. Since The National Commission on Excellence in Education declared our "Nation At Risk" (1983), we have been awash in education reports and plans and proposals of all kinds. Trying to stem "the rising tide of mediocrity," we increased education spending by 40% in inflation-adjusted dollars. Most states instituted higher standards, increased graduation requirements, and implemented student and teacher testing programs. Most schools adopted tougher academic and attendance standards. But all of this produced small gain. NAEP (National Assessment of Educational Programs) scores inched up slightly in math and

reading (primarily for poor and minority students) with the meager gains mostly in low-level literacy and arithmetic skills, instead of higher-order thinking.

Judging the Nation's reform efforts of the past decade by their results, we must conclude that they failed—unless one considers a low "D" acceptable. But we gained some important understanding over this period, and we are now smarter about changing and improving education than we were in the 80's. We have learned a good deal about what doesn't work and about the formidable tasks that must be accomplished if we are to remedy the serious education deficits we face—including the pernicious gap between the intellectual haves and have-nots. But to increase educational productivity and the quality of learning for more young people than we have ever reached before requires substantial help from many sectors of society, *including higher education*. We too need to help, and we need to respond with a sense of urgency—acting on the "lessons learned" from prior reform efforts so that the dollars and human initiatives are not again for naught.

Importantly, however, we need to respond with the awareness that higher-level learning for students will simply not occur without higher-level learning for teachers. And we need to respond also with the knowledge that all former reform efforts failed primarily because teachers were not adequately prepared for the new goals and expectations they were pressed to achieve. We must recognize also that the context of today's mandate for change differs substantially from prior ones in that earlier efforts were designed to bring about changes at the margins. They were designed for the academically talented only, or to improve the curriculum in this or that subject area, in the hope that it would in turn raise students' test scores in this or that area.

But this reform effort is unique. The context of our current press to change is the recognition that our problem is not a simple one—*au contraire*—it is a systems problem of great magnitude. Thus, the thrust of today's reform efforts is not expected to bring about gradual improvements in various parts of the education system as it now operates. Rather, it is expected to produce a substantially changed education system—one that is capable of bringing about a "sea change" in the kind and quality of results we achieve. A gradual evolutionary process of school improvement is no longer acceptable, as the public can no longer pay the consequences of its failure.

The public can no longer afford a system that fails entirely to help a third of its students learn—causing them to take to the streets. They can no longer afford a system that tolerates another third of the students staying in school, but learning so badly that they graduate unequipped for *either* work or further study. And the public can no longer afford a system that develops its best students to perform only at average levels when compared with their world class counterparts.

We need a more effective *system* of education, and to get it, all parts of the system must be open for redesign. We already know what some of these changes need to include if we are to produce significantly different *and* better results for students. But many of the changes are still unknown—yet to be devised by those who understand the current challenges and know what has been learned from the most recent reform efforts.

Lessons Learned

To prepare teachers for a changing world of work in schools, university faculty (from the arts and sciences as well as education) must join the growing public debate—rapidly a mandate—for new teaching and learning. Of the "lessons learned" from early reform efforts—perhaps the most critical, and yet the one most dangerously close to being repeated—is that *more-of-the-same does not equate to better*. More time spent teaching and learning the same old stuff in the same old ways just doesn't work. It is, in fact, counterproductive.

The paradigm of "*teaching as telling, learning as listening, knowledge as facts, and tests as memory samples*" is no longer viable for education (neither in the schools nor in the colleges). Such a paradigm served society when knowledge was developed and applied very slowly; when it was recorded and transferred through expensive labor-intensive processes; when there was less to learn then there is today. It served a society that needed more muscle power than mind power. It served a society that was content to have its schools be sorting systems—places that operated to select the most highly motivated students from among those who showed up predisposed to learn what the school had to offer. This paradigm served a society that had not advanced its understanding of learning or pedagogy well enough to move out of a very primitive state. But all of these circumstances have changed.

Information and knowledge is now produced, stored, retrieved, and distributed at great speeds. Knowledge has come to be viewed as dynamic rather than static. People expect to learn for a lifetime, instead of "having it done" by graduation. Employers seek high level thinkers and problem solvers—people prepared to work effectively within a pluralistic, global society. Democratic rule has advanced such that an equity agenda of considerable power now rallies against schools as sorting systems, or places that discriminate against persons because of race, gender, class, or ethnicity. Policymakers now expect that all students can learn and that educational institutions will provide a fair and reasonable opportunity for learning. And new knowledge from R&D on teaching and learning have produced powerful new insights and practices for greatly improved learning.

We now know, for example, that more ambitious learning goals for students require more ambitious forms of pedagogy. We have learned that more ambitious pedagogy can produce better learning outcomes for more students than we have ordinarily reached—but it requires elementary teachers to have much greater depth and flexibility with the subjects they teach. Similarly, the more ambitious, flexible pedagogy requires a longer period of development and practice than was needed when teaching was simply telling—and it must necessarily be learned in schools that support these new practices. We have also learned that the more ambitious pedagogy cannot be sustained over time, since it is extraordinarily labor intensive. New tools and teaching arrangements must now be developed to lighten the burden of teacher's work, so that the new learning gains for students will not have to be compromised.

We have also acquired other important insights. For example, the extent to which students can memorize information and "appear" to know and understand what was intended—when in fact they don't get it all—has been an important new discovery. The power of misconceptions, as well as the need to devise lessons for "unlearning" faulty assumptions before teaching new concepts for understanding, is another such insight. Cooperative learning among students as a powerful means of engaging their thinking around important ideas is another. When employed properly, it increases recall, flexible thinking, motivation for learning, and responsibility for others—concomitantly it provides a constructive alternative to tracking. These and related insights now make better learning for more students possible. Most of them emphasize the importance of teachers' devising and guiding students through powerful learning tasks—tasks that enable students to "make meaning." Such tasks help teachers connect the new important learning with each student's prior learning, while keeping them actively engaged in the learning process instead of letting them be passive recipients as with the dominant paradigm.

We have also learned that students' learning in school cannot be divorced from their learning outside of school. What is taught in the home and community either helps or hinders what is learned in school (and vice versa). Thus, what and how much children learn—as well as how well or how badly they perform on school-administered tests—is a reflection to their opportunities for learning in both places. The "bottom

line" of their learning, therefore, cannot be left at the feet of the educators alone. The responsibility must be shared with parents and community members who advocate on behalf of children and youth. Schools and the teachers in them are now expected to help build local support networks at the school–community nexus—networks that afford at-risk children quality learning opportunities before and after school, as well as during school hours.

Teachers now need to be "linkers" in some sense—able to make connections with parents, other community members, and human resource professionals who serve the direct or indirect learning needs of children and youth. Learning opportunities for students need to be complementary—both within the school and between the in-school and out-of-school settings. The adults sharing responsibility for students' learning are increasingly expected to work in teams on behalf of the young people they hold in common. This added responsibility for teachers affects their standard isolated role in the classroom. Now they collaborate more with their school colleagues and community counterparts (i.e., not only with other teachers in the school, but with parents, other family members, and other human service professionals in the community) who also influence students' learning. Teamwork skills and competence in collaboration for the best student learning possible are increasingly critical qualities for good teachers.

Similarly, we have developed new insights and understanding about teacher learning. We have learned that pedagogical knowledge cannot be taught effectively independent of the subject matter. We have learned that students who major in various subjects at the university often lack knowledge of the content they are expected to teach in the elementary and secondary schools. We have discovered more about the nature and importance of "pedagogical content knowledge" for teacher judgment and decision-making—i.e., knowledge of students' thinking about particular concepts and ideas (at various ages and from different cultures) *and* the pedagogical implications for learning.

We have learned that prospective teachers cannot learn to integrate and apply effectively the intellectual and practical skills of teaching in a couple of months (assuming high-level learning *and* students who don't come to school already motivated and knowledgeable about the subject). (Parenthetically, even barbers have longer periods of apprenticeship than most would-be teachers.) We know that when teaching is not simply "telling," and learning is not simply "listening," and mastery is no longer conceived as "regurgitating facts"—and when effective teaching requires bringing about learning for those who are culturally different from oneself and when effective teaching requires bringing about learning for students who are reluctant to learn what the school has offer—then we must help prospective teachers develop and learn over a prolonged period of time in highly supportive teaching environments. But most of our colleges do not operate on these new insights. They are stuck in the old patterns of preparing teachers for an earlier, simpler era. They too are stuck in their old paradigms.

Why Is Education Stalled?

The most common educational cliché of the day focuses on readiness for the 21st Century. And most professional fields pursued by today's college graduates *are* ready—for while they continue to adapt to a rapidly changing environment, they have already transformed themselves dramatically. Since early in the century, they adapted steadily to new demands, to new technologies, and even to a growing acceptance of human diversity. For better and sometimes for worse, most fields "modernized." The transportation field left the horse and buggy early in the 20th Century, replacing it with autos and aircraft of great sophistication. The communications field was revolutionized, as sound and then pictures were captured and shared at such speeds that we watched our most recent war on television as it occurred—and so with the medical field, and architecture, banking, anthropology, engineering, criminal justice, and so on. These professions,

and the work of the practicing professionals in them, have been fundamentally altered, such that neither practicing nor future professionals expect to work as their counterparts did at the turn of the century.

Except for teachers. College graduates pursuing careers in teaching today find conditions of work almost identical to those public school teachers encountered in the early 1900's. The dominant work is confined to a classroom; the primary technologies are still chalk, eraser, and blackboard; the major means of communication remain out-of-date textbooks and lectures from educators equally dated because of little opportunity for staying abreast of changes in their field. Novice professionals with minimal experience and training are still given the most difficult teaching and learning assignments. And with modest exception, the instructional setting for teachers is not just "low tech"—it is basically "no tech," for most teachers do not even have phones to keep up with the growing demand for closer work with families and community.

So why is this the case? Why is teaching not only unready for the 21st Century—why is it stalled in the early 20th Century? There are a number of reasons, such as the sheer size of the undertaking (educators constitute the largest of the "learned" professions in the United States) and its widely dispersed zones of responsibility (shared control across local, state, and national governments). But one of the primary inhibitors is the absence of a systematic approach to sound innovation.

Huge sums of money are invested in carrying out the sprawling education enterprise as it currently operates—while practically no monies are invested in responsible innovation leading to cumulative, ongoing improvement. The history of efforts to change education does not inform contemporary decision-makers.

Piecemeal solutions drift in and out of style as various ideologies sway popular opinion, leaving a vast array of fads swept over the education landscape. Quality definition stays effusive *and* illusive. The meager R&D investments that are made available remain sporadic and disconnected from established ties with existing education policy and practice.

Most of the universities conducting the bulk of the research and development in the U.S. give short shrift to teaching. And what R&D they do contribute is focused primarily (some argue "excessively") on the problems of the current system as it now operates—a system that we already know is broken. Existing investments neglect applied research and do not build on the things we already know and understand. They denigrate development and discovery work that is geared to the design and study of new models and systems that could produce the results needed for teachers to be successful education professionals in the 21st Century.

So What Are We To Do?

Preparing teachers for a changing world of professional work in schools—changes for which we have only limited examples and others for which we have only broad general outlines and sketches--is a trick. It is tricky also because the collegiate sector is largely about teaching and learning as well, and it too is engaged in the struggle to update and improve learning services for the collegiate student population. Changing teacher education in the schools *and* on our college campuses at the same time—*while* helping to figure out what we should be doing to improve on the current learning circumstances in both places at once—sometimes seems impossible. But it is not.

We Must Collaborate

Faculty responsible for the education of teachers (university faculty in the arts and sciences, university faculty in education, and school faculty from selected clinical sites) must tackle the challenge together. The task is too big for any one of these groups alone—and no single group has the range of talent and expertise that is needed to do it well. Further, a blending of the diverse perspectives brought by disciplinary scholars, education scholars, and practicing

professionals produces a synergy and more effective program for intending teachers than is possible if tackled by one group alone or by each group in isolation from the other. But collaboration does not mean everyone doing everything together.

It is important for the three groups to work together initially to work out a general consensus on goals—so that the individual and collective efforts are headed in the same new directions. Working out an intelligent division of labor is also critical—a division that respects and draws on one another's talent and expertise. A means of connecting the efforts regularly must also be devised (through some mechanism such as faculty cohorts or academic alliances) to ensure that the goals and understandings remain compatible and the results of the respective contributions combine into coherent, high quality teacher education. The most effective collaborations typically focus as much on the R&D that informs faculty insight regarding quality teaching and learning as they do on the learning opportunities designed to prepare prospective teachers for a changing world of teaching and learning. Collaborative inquiry can benefit students as well as faculty—especially when students participate in the studies of innovation and change themselves.

But disciplinary faculty should continue to do what they do best, which is to remain current through work and study at the edge of their disciplines. For a number of the disciplinary faculty, however, this work should include applied study of the discipline as it is shaped and formed during teaching and learning in various contexts—for students of different ages and stages of development (e.g., elementary, secondary, and collegiate) or for students of different linguistic or cultural backgrounds, or for students applying the discipline to various problems and in different situations. Faculty inquiring about these disciplinary applications and extensions are key participants in the teacher education program.

Since process and content become one when you are teaching teachers, disciplinary faculty must work on behalf of quality teaching and learning experiences for students studying the discipline in their department—and especially for those who are themselves learning to teach the discipline. Disciplinary faculty must take the lead in studying, proposing, and working through the system the appropriate disciplinary majors and minors students of teaching ought to pursue. Ideally, strong faculty in the disciplinary departments (often, but not always, those studying teaching and learning) would participate actively in a faculty cohort for prospective teachers (with education and clinical faculty). Often managed through the ed school, a faculty cohort follows a student cohort (a modest-sized class) of prospective teachers from their time of entry through graduation. Disciplinary members of a faculty cohort share responsibility for program design, teaching, and evaluating students' learning and opportunity for learning as it relates to the discipline. Thus, for example, they assess carefully the qualifications of the clinical faculty members who are asked to join the cohort, for they will represent the teaching of the discipline in the schools when the teacher candidates are placed there for practicum learning.

As with the disciplinary faculty, faculty from the education school contribute what they do best—which is to stay abreast with what is happening at the edge of the field in elementary and secondary education (in the U.S. and abroad). Through research and study, they maintain sound understanding of school learning and the policies and practices that affect its quality. They bring to the faculty cohort grounded knowledge of past and current challenges in the education of children and youth—and a commitment to address these challenges in the professional education component of teacher preparation. They assume responsibility for maintaining strong connections and program coherence with the students' learning in the schools, the disciplinary departments, and in the ed school itself—connections with high coordination costs if quality learning laboratories (such as professional development schools) are maintained in real communities for applied R&D,

demonstration of good practice, and teacher's practical learning.

In many places, education faculty manage admissions, orientation, advising, and licensure testing of students—in addition to the important socialization experiences that accompany quality professional education in all fields. But the primary responsibility of education faculty is to ensure program integrity and coherence overall. Toward this end, they must develop, organize, and teach knowledge and skill related to effective teaching practice and policy—and where aspects of such knowledge are best obtained elsewhere (as in the disciplinary departments or in the schools), they turn to other faculty, but work with them to ensure program quality. The education faculty bear a special responsibility to be especially good teachers themselves and to advocate for quality teaching throughout the university. They also must teach particular areas of professional study that are not typically made available through the disciplines or the schools—such as educational inquiry, educational criticism, and an emphasis on equity and social justice through education.

The clinical faculty have been the most neglected in teacher education, although this circumstance is changing. Their influence is substantial, and their help is critical if we are to prepare teachers for a changing world of work. Since the requirements of the new teaching and learning necessitate prospective teachers' learning over time with mentors and school settings that support changing standards and sensitivity to a changing school population, it is likely that we will have to invest heavily in selected school sites. In many ways "today's schools are not the right places for preparing tomorrow's teachers," since the old teaching and learning paradigms predominate in most places (as they do in most universities). Intensive work with the staff of innovative schools can be both efficient and effective in the long run, however, especially if the faculty participate actively as respected collaborators in the faculty cohort.

The three sets of faculty—from the disciplinary departments, from the ed school, and from the elementary/secondary schools—together can invent better practice for teachers and teacher educators. Our country needs desperately to break the cycle of repeated failure in attempts to improve learning in America. Our research capacity, our spirit of innovation, and our awareness that teachers are at the heart of our search can bring us together. Unless we do, America will simply not get the quality of teaching and learning and schooling that we need.

Workshop Day I: Thematic Panels

W.A. Sibley, The University of Alabama at Birmingham, Co-Chair

Instructional Innovation

George P. Moore, Chair

Panel Members: Sarah B. Berenson (North Carolina State University), M. Darby Dyar (University of Oregon), Mario J. Gonzalez (The University of Texas at Austin), Steve P. Landry (The University of Southwestern Louisiana), Donald R. LeTorre (Clemson University), David W. Mogk (Montana State University), Gillian M. Puttick (Technical Education Research Center, Cambridge, Massachusetts), Helen R. Quinn (Stanford Linear Accelerator), Fred S. Roberts (DIMACS, Rutgers University), Barbara Sawrey (University of California, San Diego), Sidney Simpson (University of Illinois—Chicago), David Sokoloff (University of Oregon), Dorothy L. Stout (Cypress College), Sylvia Ware (American Chemical Society)

Introduction

We meet here to address one facet of the general crisis in education, the preparation of science and math teachers for elementary, middle, and high schools and, specifically, the role that college and university faculty might play in better preparing our students to become teachers.

We generally think of American colleges and universities as equal or superior to those of any country. In these introductory remarks, therefore, I comment on two paradoxes posed by our purported position of pre-eminence.

First, if there is a "crisis" in education, why is it so difficult to identify clear, forceful, and imaginative responses from our colleges and universities to a situation that could prove so ruinous to them, and about which they have complained for decades? When we search for "innovations" and reforms in teaching, why don't dozens of examples come to mind?

Second, if there is a persistent crisis in the training of students at pre-college levels, and if performance scores have declined over such a long period, how is it that our schools of higher education still enjoy such a high reputation? How is it that they have not been eroded by those very declines?

In an attempt to provide at least some partial answers to these questions, I will argue below that our institutions of higher learning have been preoccupied with their own fiscal crisis, and that their actions have been largely directed to that crisis. Because their reputations have largely been spared, they have yet to address their own serious educational problems, which are, admit-

tedly, harder to perceive than those at the pre-college level which have gained international attention.

I will argue that professional societies, more clearly perceiving the implications of the crisis and responding with concern and vigor, have become the initiators of educational reform and the guarantors of standards. In the short term, this has been largely beneficial and is indeed one of the factors that has helped preserve the integrity and reputation of our schools. But at the same time, by its default the university community has surrendered a primary responsibility to outside agencies with rather different goals.

I will also argue that the reputation of our universities has also been largely spared by historic and unprecedented demographic shifts that mitigate, for the moment, the effects of the decline in pre-college educational performance.

These factors help to explain the relative indifference and insensitivity shown by our colleges and universities to what all of us recognize as a very serious threat to our society. This meeting helps remind us that it is perilous and short-sighted to ignore threats to education at any level.

I.

The likelihood that colleges or universities will introduce relevant reforms in teaching or teacher preparation can be gauged from the relative priority given to teaching at the university level itself.

For maximum personal benefit, most university professors currently allocate their "disposable" time to research: promotions are pegged to research "productivity" and, increasingly, to the sheer size of individual grants (in dollars); salaries are pegged to promotions; and grant support and research productivity are reciprocally linked. Here, both universities and funding agencies direct our rational priorities in the same direction: away from teaching.

Educational institutions neither clarify the relative priority of teaching, nor generally reward our concerns for education. Indeed, universities are themselves caught in a dilemma in the relative priority given to teaching versus research.

If the education they provide is better than that at other institutions, then they should attract more students. Given the financial situation of most private colleges and universities, teaching then ought to have a high priority. (This argument does not work as well for a public university such as the University of California which is forced to turn away many qualified applicants who appear unconcerned with its reputation for assigning teaching a low priority.)

But if the price of better teaching is less research, then the same schools stand to lose the high overhead payments linked to research grants and may, in addition, have to pay more faculty salaries from their own funds. The ambivalence of the educational institution toward this conflict of interest is passed down to the faculty. Students, who have paid money for their education, are understandably outraged when the priorities are clearly tipped toward research.

The point is this: In the framework I am describing, decisions by both faculty and administration are often based primarily on criteria other than educational ones. Discussions of reform are motivated by personal and commercial concerns, not by educational or societal concerns. When our universities reaffirm their traditional commitment to quality education provided by dedicated professors (which many of our finest liberal arts colleges still provide), many of the problems of education at earlier levels will be alleviated.

II.

Numerous studies confirm the fact that increasing numbers of high school (and elementary school) students are bored with science and turned off by math. This has eventually translated into fewer students entering, or remaining in, the basic sciences and mathematics in college.

Universities have reacted to this threat primarily as a marketing rather than as an educa-

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tional problem, seeking to maintain their "market share" of the best-prepared students.

A more serious programmatic response has been mounted by professional societies from individual disciplines directly threatened by sharp reductions in enrollments. These organizations now promote a variety of activities (such as summer programs for teachers) and design and encourage curricular revisions for the lower grades that they hope will provide a continuous supply of incoming college majors, and curricula for colleges that will help to retain them once they are there. Initiatives for reform, in other words, have been championed by forces outside the university.

Thus, responses to real and threatened reductions in undergraduate enrollments have grown out of a sense of departmental or disciplinary loyalty, not out of a more general commitment to education or to educational institutions. In some respects this is entirely defensible and represents a concerted effort to maintain high standards and disciplinary integrity in spite of eroding forces.

In some cases disciplinary loyalties have superseded and undermined university loyalties, and the venality of the university has even occasionally reinforced the trend. My own university, for example, instituted fiscal "reforms" that inadvertently pitted one department against another. Instead of directing our students to take math courses from the math department, for example, we could offer, and then require, a comparable course so that we would benefit directly from the tuition dollars. There was no presumption that we would *teach* a better course than the math department, thus *earning* the dollars. But by imposing fiscal, as opposed to educational considerations on each "revenue center" (as departments were renamed), the university betrayed the essential concept of a university.

But there are other serious consequences of encouraging outside professional societies, by default, to define and direct educational goals. At this conference, the argument was made repeatedly that if we simply improve our college teaching we automatically improve the preparation of teachers. If we teach chemistry better, the argument goes, then future high school chemistry teachers will be better prepared. Of course there is merit to this argument. But it avoids the deeper question of how best to prepare *teachers* and hides a potential conflict of interest behind a plausible conceit. The proposition that a chemistry curriculum designed best to prepare chemists is also best to prepare high school chemistry teachers remains dubious and untested.

III.

One would expect that students, bored with science and math classes, both in high school and in college, would tend to move into other fields. But to attribute enrollment reductions entirely to educational deficiencies at earlier levels would be hypocritical.

Even efforts by professional societies have been unable to erase student perceptions that a bachelor's-level degree in science or math will most often lead to a boring job, if any job at all. Only in some engineering fields, perhaps, has the bachelor's degree retained any value, and even that may now change. Conceivably, biology degrees may become more valuable as environmental concerns translate into more jobs, but the interest, rewards, and stability of those jobs remains to be demonstrated.

What does that leave? A postgraduate degree becomes the logical step. But students quickly learn from their peers, if not from their professors (who may have an interest in obscuring the realities), that there is an army of underemployed postdocs that cannot possibly be absorbed by industry and that an academic position, once considered idyllic but now seen as extremely stressful and unrewarded, will not even be an option except for a few.

Increasingly, for these and other reasons, native-born Americans do not go to graduate school, or, if they do they tend to enter business or legal programs rather than programs in science and mathematics. Ordinarily, faculty would have perceived this as a direct and imme-

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diate threat to their research interests and responded accordingly. But our graduate science, engineering, and math departments are increasingly filled with foreign students who, with foreign-born postdocs, now conduct the research of this country. They also fill the teaching void as professors spend less time teaching. This demographic shift has prevented the educational crisis from translating into a research crisis, and this is the primary reason universities and colleges have found it unnecessary to make systemic changes.

We have borrowed low-wage scholars from abroad to cover an educational deficit just as we have borrowed dollars to cover our fiscal deficit. If only we could borrow undergraduates as well! Unfortunately, students from abroad come generally from developing countries and lack tuition dollars. In graduate school their tuition is covered in large part by the grants or teaching assignments to which they are indentured.

This remarkable rearrangement should cause great concern. For one thing, foreign students, being relatively unprotected, are easily (and frequently) exploited in ways that native-born students would reject with outrage. Furthermore, this arrangement concentrates students in currently funded research areas, further destabilizing the intellectual balance of our scholarly base. And, most important, this arrangement, by compensating for underlying educational deficiencies, invites us to postpone the inevitable confrontation of them. In subsidizing this transition, agencies such as NSF and NIH have become major direct forces in reorienting university fiscal (and thus, indirectly, educational) policy, without responsibility or accountability for the consequences of their actions.

IV.

Where does this leave us in the matter of the role of colleges and universities in improving teacher preparation? After all, many of us at this meeting come from research universities that have divested themselves of all teacher training. Some of us even come from departments, such as engineering, that traditionally do not produce teachers. Many of us, as I have tried to point out, teach to serve the discipline and neither give thought to the special problems and aspirations of teachers, nor encourage our students to enter the teaching profession.

Coming from an environment in which teaching is considered a burden (as in the phrase "teaching load"), many of us consider teaching as the price to be paid for being in a research institution, and scheme to reduce that price to a minimum. Understandably, then, it is hard for us to conceive of anyone who would *want* to be a teacher, especially a teacher of students who did not express a nominal commitment to the subject being taught. And certainly not for the kind of money being offered.

Others at this meeting come from colleges that actually do the bulk of teacher training. In response to budget cuts, those colleges, at least in California, are trimming their faculty and overworking the remaining teachers. Faculty reductions, in turn, necessitate reductions in course offerings, so that what used to be a five-year teacher-training curriculum now takes six or more years to complete. Hardly an environment that would encourage or even countenance innovations except those that compensate, at little or no cost, for a sheer loss of teachers and teacher–student time.

Others at this meeting, speaking a strange tongue, come from the "education industry" and are understandably anxious to increase their contact, interaction, and influence with college and university faculty, but sometimes encounter a combination of disinterest, skepticism, and suspicion in response. For them, education research is a primary professional concern, not just a marginal one.

Representatives of these diverse groups make up the body of this meeting, and there is much we can learn from one another in dealing with the urgent and difficult problems we face. The presentations at this and other panels show that ideas abound for innovation in teaching. Some of the innovative ideas presented here, but fewer

than expected, take advantage of new technologies. Some use existing technology in unexpected ways. Some offer new modalities of teaching where student interactions facilitate learning. Others utilize older educational values and techniques in new ways. Inevitably, all are likely to be most successful in the hands of exceptional teachers, and we were fortunate to have some exceptional teachers here to demonstrate their methods.

But underlying the enthusiasm and genuine interest that greeted these innovations, one sensed a deeper concern about the extent to which innovations alone would make a significant impact in the absence of fundamental change in educational philosophy.

Would our colleges and universities ultimately see in the present crisis a clear mandate for change? Would individual departments and faculty be prepared to make the necessary adjustments? Would they even respond to rewards offered as inducements for change? Would taxpayers, boards of education, and teacher organizations support the political and fiscal reforms that make educational reform possible?

Would we finally respond as if there were *really* a crisis?

Engaging Students with Microcomputer-Based Laboratories and Interactive Lecture Demonstrations[1]

David R. Sokoloff, University of Oregon

I. Introduction

This activity introduced panelists to the use of microcomputer-based tools to enhance student learning of physics concepts. These tools have, since 1986, been the basis of a highly interactive laboratory curriculum, *Tools for Scientific Thinking*, designed for secondary and introductory college-level physics students, and, more recently, as a means of engaging students in large lecture sections through *Interactive Lecture Demonstrations*. Panelists had an opportunity to experience both of these modes of instruction as applied to force and motion concepts and were also presented with some of the evidence for their effectiveness.

Results from research in cognitive science and education substantiate the importance of basing development of scientific concepts and skills on concrete experience.[2,3] The *Tools for Scientific Thinking* project [4-6] at the Center for Science and Mathematics Teaching at Tufts University has developed microcomputer-based laboratory (MBL) tools and curricula that can help students make connections between the physical world and the underlying principles which constitute scientific knowledge. These materials provide a convenient and effective means for collecting and displaying physical data in a form that students can remember, manipulate, and think about.

MBL tools of the style used by the panelists, were first developed at the Technical Education Research Centers (TERC) for use at the middle school level.[7] More recently, tools for Macintosh and MS-DOS computers have been developed at the Center for Science and Mathematics Teaching at Tufts University and Dickinson College.[8] They make use of inexpensive probes, connected to a Macintosh or MS-DOS computer through a Universal Laboratory Interface (ULI), to measure such physical quantities as temperature, position, velocity, acceleration, force, sound pressure, light intensity, magnetic field, current, and voltage.

Students are not required to know anything about computers to use the MBL tools. Menu-driven, self-explanatory software is friendly, even for first-time users, and encourages underprepared and anxious students. Students are in control of their learning since they select the measurements to be made and the way the data are displayed. Data are displayed in digital and graphical form on the computer monitor as the measurements are taken. Students can transform and analyze the data, print graphs or tables, or save data to disks for later analysis. The tools do not simulate physical phenomena, but instead are a means of changing inexpensive computers into instruments for student-directed exploration of the physical world.

The following characteristics of these tools are important to student learning. (1) The tools allow student-directed exploration but free students from most of the time-consuming drudgery associated with data collection and display. (2) The data are plotted in graphical form *in real time*, so that students get immediate feedback and see the data in an understandable form. (3) Because data are quickly taken and displayed, students can easily examine the consequences of a large number of changes in experimental conditions during a single laboratory period. The students spend a large portion of their laboratory time observing physical phenomena and interpreting, discussing, and analyzing data. (4) The hardware and software tools are general—independent of the experiments. The variety of probes use the same interface box and the same software format. Students are able to focus on the investigation of many different physical phenomena without spending a large amount of time learning to use complicated tools. (5) The tools dictate neither the phenomena to be investigated, the steps of the investigation, nor the level or sophistication of the curriculum. Thus, a wide range of students from elementary school to university level are able to use this same set of tools to investigate the physical world.

II. The Motion Detector, Force Probe, and MacMotion *Software* (Motion *for MS-DOS)*

The tools used for teaching force and motion concepts are the motion detector and force probe. The motion detector is a sonar device which—in conjunction with the software—plots the distance to an object as a function of time. Velocities and accelerations calculated from the distance data can also be graphed. The motion detector is able to detect and display graphs of the motion of *any* object. Thus, instead of using complex apparatus, the motion detector may be used to measure the motion of simple, common objects such as toy cars and even the motion of the students themselves. There is no other way of accurately displaying such graphs, certainly not in real time. Figure 1 shows a velocity–time graph for a student walking away from and then toward the motion detector.

The force probe is a device which translates forces on a flexible diaphragm into a digital signal through the use of a small magnet, a Hall effect sensor, and the ULI. The software and ULI enable students to collect and graph data simultaneously from both the motion detector and force probe. Thus measured forces may be applied to objects, and the motion of the objects may also be measured. Figure 2 shows the velocity–time and force–time graphs for a cart pulled along a smooth table by a falling mass attached to the cart by a string.

The scales of the vertical and horizontal axes may be changed before or *after* the data are collected. Students who in the past plotted graphs in the corner of a large sheet of graph paper soon learn to make readable graphs—a general purpose skill, useful in many disciplines. The software allows one set of data to be displayed on the screen while a new set of data is collected and graphed for comparison (perhaps after a slight change in experimental conditions). Numerical data are available in tabular form

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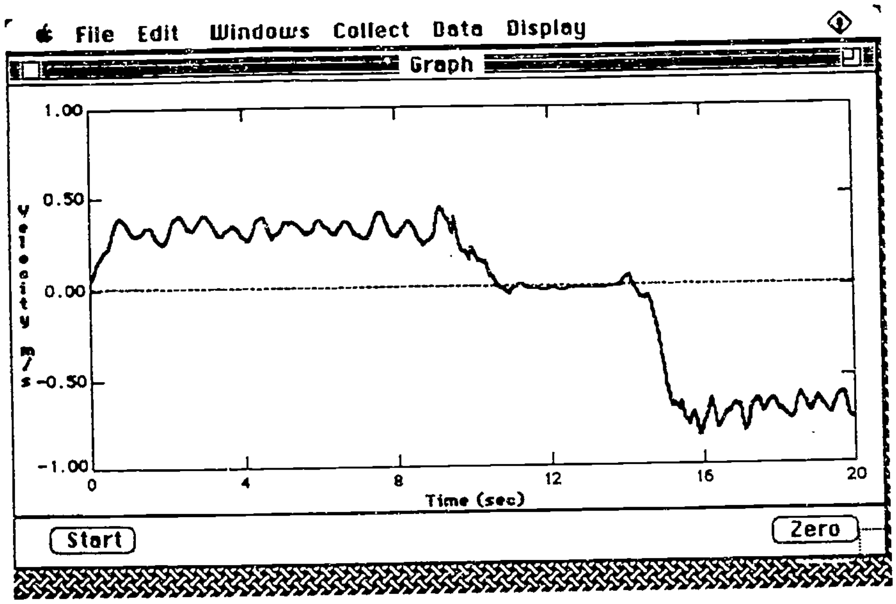

Figure 1. Velocity graph plotted from data collected by the motion detector for a student walking away from and then toward the motion detector.

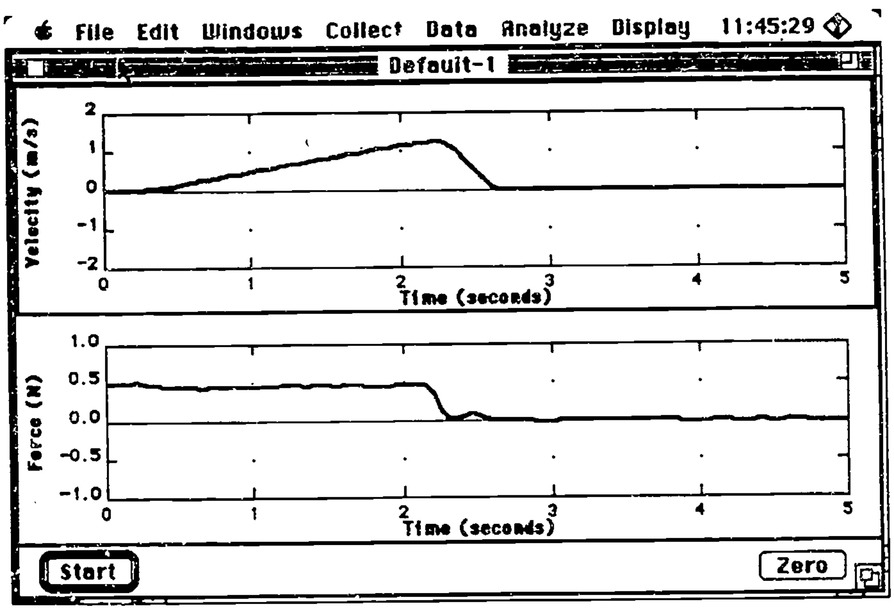

Figure 2. Graph of velocity and force vs. time for a cart pulled along a smooth table by a falling mass attached to the cart by a string.

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(which can be pasted into a spreadsheet) or can be read directly from the graph using the analysis software feature which presents digital values corresponding to the position of a movable cursor on the graph. Complete statistical data analysis and curve fitting are also available.

III. *The* Tools for Scientific Thinking *Force and Motion Laboratory Curriculum*

These tools have made possible the *Tools for Scientific Thinking* curricula for university and secondary school students developed by the Center for Science and Mathematics Teaching at Tufts University.[9] These discovery-based laboratory curricula allow students to take an active role in their learning and encourage them to construct physical knowledge from actual observations. They make substantial use of the results of educational research.[10] The curricula have the following features. (1) They use a guided discovery approach with groups of two to four students. (2) Peer learning is supported by presenting data immediately in an understandable form. (3) Predictions are used to engage the student and provide a vehicle for discussion. (4) Attention is paid to student alternative understandings that have been documented in the research literature. (5) They encourage students to construct knowledge for themselves.

The MBL curricula have been designed to be incorporated into traditional introductory physics courses found at most colleges and universities, where laboratory sections are often taught by teaching assistants with varying pedagogical skills and where lecturers pay little attention to the laboratory. In place of the classroom discussions—which under the best of circumstances would be used to consolidate the concepts learned in laboratory—each laboratory is accompanied by a homework assignment.

Panelists had an opportunity to experience some of the introductory parts of the *Force and Motion* curriculum which make substantial use of students' own body motions to teach kinematics concepts. A sample exercise is shown in Figure 3. Figure 1 shows the velocity–time graph corresponding to this exercise. The curriculum consists of five laboratories, two on kinematics, one on passive forces, one on Newton's Laws of motion and one on periodic motion. More details are available in the References.[4 and 9]

IV. *Interactive Lecture Demonstrations*

While the microcomputer-based tools and *Force and Motion* laboratory curriculum have been shown to be effective in enhancing student understanding of force and motion concepts in the laboratory,[4] can anything be effective in engaging students in large lecture sections? During 1991–92, an experiment with microcomputer-based interactive lecture demonstrations was attempted at the University of Oregon.[11]

The following is the protocol for an interactive lecture demonstration. (1) The demonstration is described and carried out without MBL measurements. (2) Students discuss the demonstration in small groups. (3) Each student sketches a prediction for the outcome of the demonstration on a sheet which will be collected (but not graded). (4) The demonstration is carried out with the MBL graphs displayed. (5) The results are explained in the context of the demonstration. (6) Analogies with similar physical situations are discussed.

Figure 4 shows several examples of interactive lecture demonstrations designed to teach force and motion concepts which the panelists experienced during the workshop. Figure 5 shows excerpts from the student hand-in sheet corresponding to these three demonstrations. Figure 2 shows the graphs corresponding to Demonstration #2.

Besides directing students' attention to the demonstration, the protocol engages students in the same learning sequence of collaboration, prediction, and explanation used in the laboratory curriculum. The requirement that students commit themselves to a written answer seems to be effective in getting them to take ownership

of their preconceptions about force and motion. The contrast between their predictions and the actual results of the demonstration causes a strong dissonance which must be resolved. In this way, true constructive learning appears to take place.

V. *How Effective Are These Teaching Methods?*

Over the past several years a study has been carried out on the effectiveness of the *Tools for Scientific Thinking* laboratory curriculum and the Interactive Lecture Demonstrations. A *Force and Motion Diagnostic Test* has been developed, which contains 33 multiple choice and several open-ended questions. Figure 6 shows one set of questions from the test, the *Force Sled* questions. The test includes a variety of other questions on kinematics and dynamics.[12]

Pre- and posttesting have been carried out in the noncalculus General Physics course at the University of Oregon. This four-credit-hour course enrolls about 350–400 students each term, divided between two lecture sections. The class meets for four lectures each week, with no recitation. One-half to two-thirds of these students are also enrolled in the Introductory Physics Laboratory, a separate two-credit-hour course.

In 1989 and again in 1990, the *Force and Motion Diagnostic Test* was given as a pretest (before traditional lecture instruction) and as a posttest (on a midterm examination, after all traditional lecture instruction). The results are shown as error rates on the *Force Sled* questions in Figure 7. It can be seen that traditional instruction had little effect on the students' grasp of these concepts. Closer analysis shows that students are using definite models in answering these questions. The most common answers on the posttest (see Figure 6) show a definite Aristotelian model with applied force correlating with velocity instead of with acceleration.

During fall 1991, the students were exposed to two 40–45 minute sessions of Force and Motion Interactive Demonstrations in lecture in addition to the traditional instruction. Also, the laboratory students were exposed to four *Tools for Scientific Thinking* MBL's. Figure 8 shows the sequence of instruction. Figure 9 shows the test results for students enrolled in lecture and lab, while Figure 10 shows the results for students enrolled only in the lecture. Significant learning gains are apparent for the lab students from both the MBL's and interactive lecture demonstrations, and for the lecture-only students from the small amount of intervention with interactive demonstrations. Excellent retention was also demonstrated with the results using other questions on the final examination.

VI. *Conclusions*

There is now considerable evidence supporting substantial, persistent learning of very basic force and motion concepts through the combination of easy-to-use microcomputer-based tools and the research-based *Tools for Scientific Thinking* introductory laboratory curriculum. More surprising are the significant learning gains discussed in this paper brought about through relatively small doses of interactive MBL lecture demonstrations in large lecture classes.

Besides use in standard college-level physics courses, the laboratory materials have been used successfully with preservice teachers[13] and disseminated to an increasing number of secondary teachers through extensive inservice workshops.[13,14]

Acknowledgments

The author wishes to thank Ronald Thornton and Priscilla Laws for their fruitful and enjoyable collaboration and support on these projects.

3. <u>Predict a velocity graph for a more complicated motion and check your prediction.</u>

   a. Each person draw below, using a *dotted line*, your *prediction* of the velocity graph produced if you—

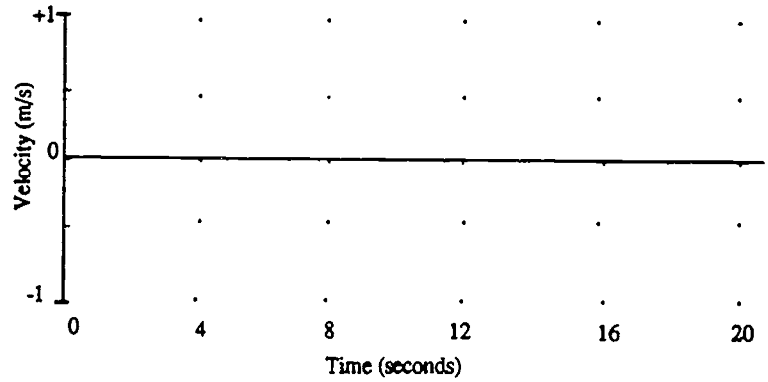
      • walk away from the detector slowly and steadily for 10 seconds

      • stop for 4 seconds

      • walk toward the detector steadily about twice as fast as before

   b. Compare predictions and see if you can all agree. Use a solid line to draw in your group prediction.

Prediction



4. <u>Do the experiment.</u> (Be sure to adjust the time scale to 20 seconds. To do this double click anywhere on the graph and change the time scale.) Repeat your motion until you think it matches the description.

   Draw the best graph on the axes below. Be sure the 4-second stop shows clearly.

Final Result

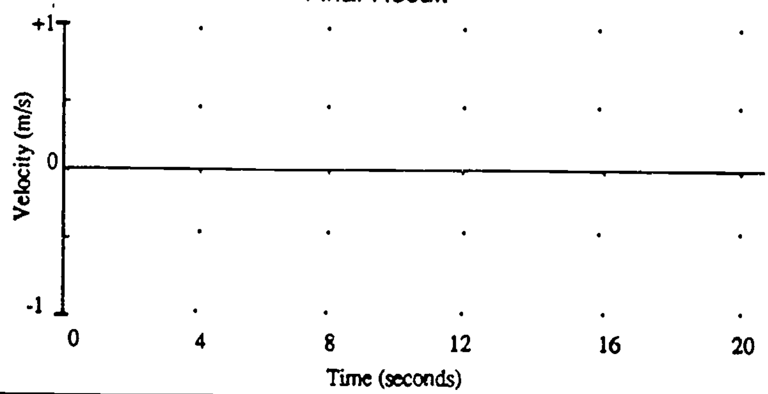
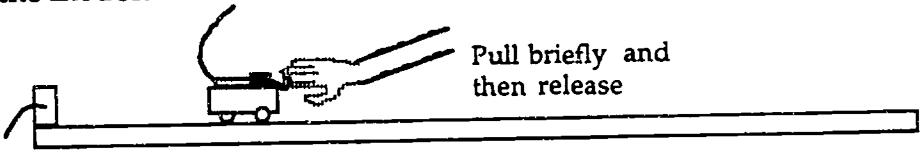
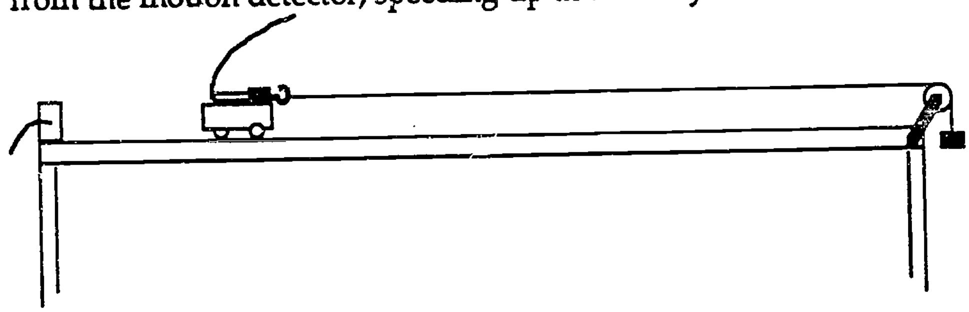


Figure 3. Excerpt from *Tools for Scientific Thinking: Introduction to Motion*. The corresponding graph is shown in Figure 1.

Demonstration #1: A cart with very small frictional force is given a pull away from the motion detector and then released.



Demonstration #2: A cart with very small friction is pulled so that it moves away from the motion detector, speeding up at a steady rate.



Demonstration #3: A cart with very small friction is given a push toward the motion detector and released. The cart moves toward the detector, slowing down at a steady rate.

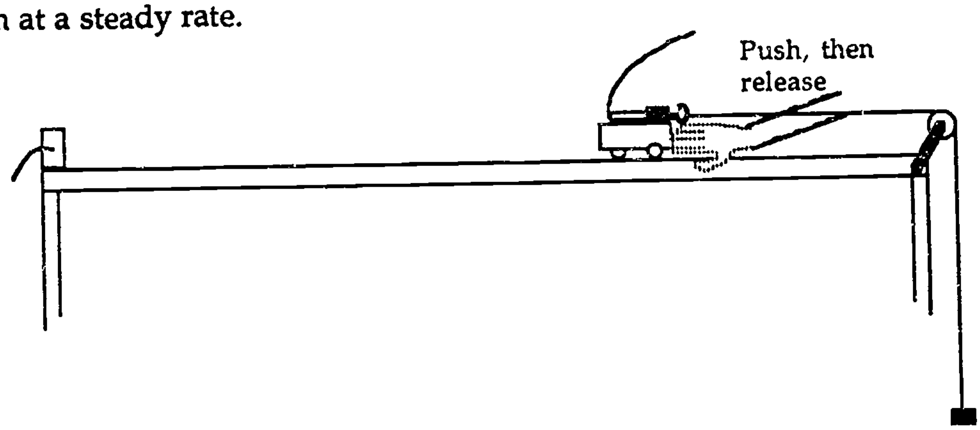
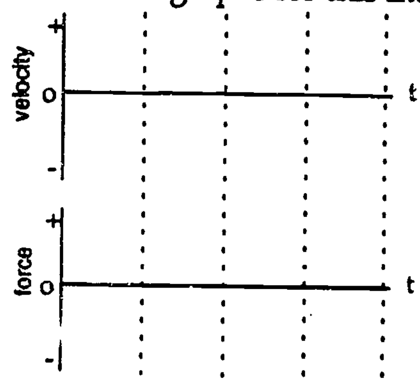
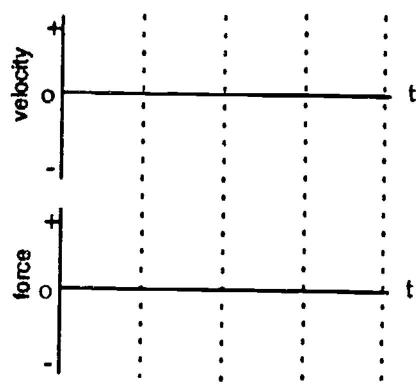


Figure 4. Examples of interactive force and motion demonstrations. The graph corresponding to Demonstration #2 is shown in Figure 2.

Demonstration 1: A cart with very small friction is given a pull away from the motion detector and then released. Sketch below your predictions of the velocity-time and force-time graphs for this motion.



Demonstration 2: A cart with very small friction is pulled so that it moves away from the motion detector, speeding up at a steady rate. Sketch on the axes below your predictions of the velocity-time and force-time graphs for this motion.



Demonstration 3: A cart with very small friction is given a push toward the motion detector and released. The cart moves toward the detector, slowing down at a steady rate. Sketch on the same axes above with a dashed line your predictions of the velocity-time and force-time graphs for this motion.

Figure 5. Excerpts from student hand-in sheet corresponding to the interactive demonstrations illustrated in Figure 4.

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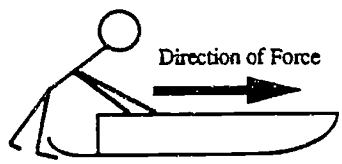
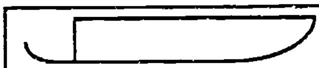
A sled on ice moves in the ways described in questions 1-7 below. Friction is so small that it can be ignored. A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the <u>one</u> force (A through G) which would keep the sled moving as described in each statement below. You may use a choice more than once or not at all, but choose only one answer for each blank. If you think that none is correct, answer choice J.



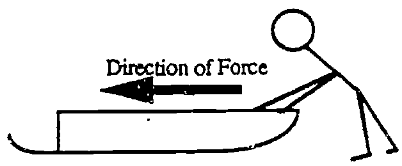
A. The force is toward the right and is increasing in strength (magnitude).

B. The force is toward the right and is of constant strength (magnitude).

C. The force is toward the right and is decreasing in strength (magnitude).



D. No applied force is needed



E. The force is toward the left and is decreasing in strength (magnitude).

F. The force is toward the left and is of constant strength (magnitude).

G. The force is toward the left and is increasing in strength (magnitude).

______1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)? **1989-90 post 68% A**

______2. Which force would keep the sled moving toward the right at a steady (constant) velocity? **1989-90 post 69% B**

______3. Which force would keep the sled moving toward the right and slowing down at a steady rate (constant acceleration)? **1989-90 post 54% C**

______4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)? **1989-90 post 67% G**

______5. The sled is started from rest and pushed until it reaches a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity? **1989-90 post 36% A, B orC--force toward right**

______6. The sled is slowing down at a steady rate but has a positive acceleration. (The positive direction is to the right.) Which force would account for this motion? **1989-90 post 42% C**

______7. Which force would keep the sled moving toward the left and slowing down at a steady rate (constant acceleration)? **1989-90 post 55% E**

Figure 6. Force Sled questions from Force and Motion Diagnostic Test. Bold type shows the most common choices on post-test in 1989–1990 research.

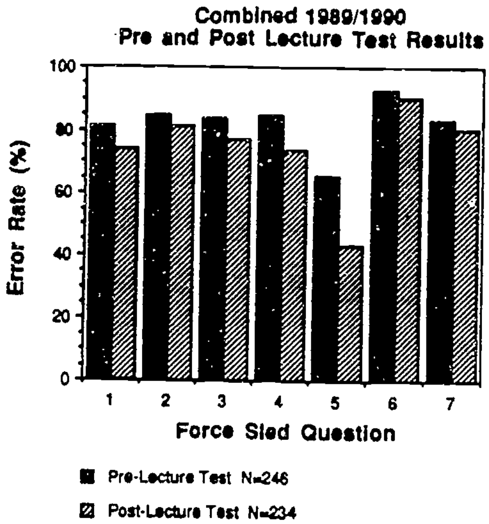


Figure 7. Error rates on *Force Sled* questions for students in noncalculus General Physics lecture at University of Oregon, 1989–1990, before and

9/23	One week of traditional lecture instruction on kinematics
9/30	PRE-TEST
9/30, 10/7	*Introduction to Motion* and *Changing Motion* MBL laboratories for LAB students; no further lecture instruction on kinematics
10/9-10/21	Two weeks of traditional lecture instruction on Newton's laws
10/14, 10/16	40 minutes of interactive MBL lecture demonstrations on motion concepts
10/21, 10/28	*Passive Forces* and *Force and Motion* MBL laboratories for LAB students; no further lecture instruction on force and motion concepts
11/4	FORCE AND MOTION PRE-DEMO TEST (POST-LAB)
11/4, 11/6	45 minutes of interactive MBL lecture demonstrations on force and motion concepts
11/8	FORCE AND MOTION POST-DEMO TEST
	No further instruction on kinematics
12/12	FINAL EXAM

Figure 8. Sequence of traditional and MBL instruction, and testing during Fall 1991.

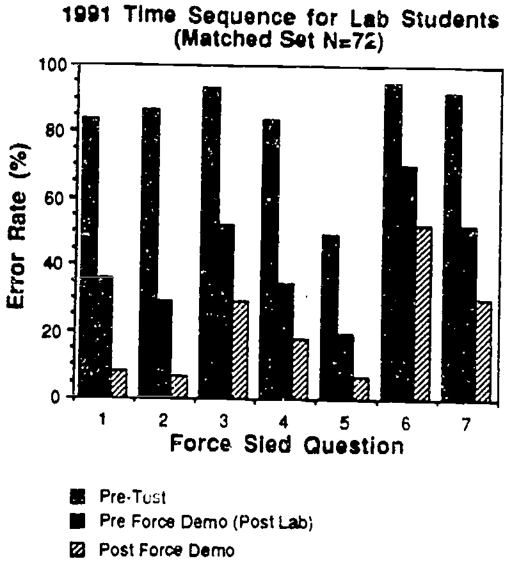


Figure 9. Error rates on *Force Sled* questions for students with lecture and MBL laboratory instruction, including interactive lecture demonstrations. The sequence of testing is shown in Figure 8.

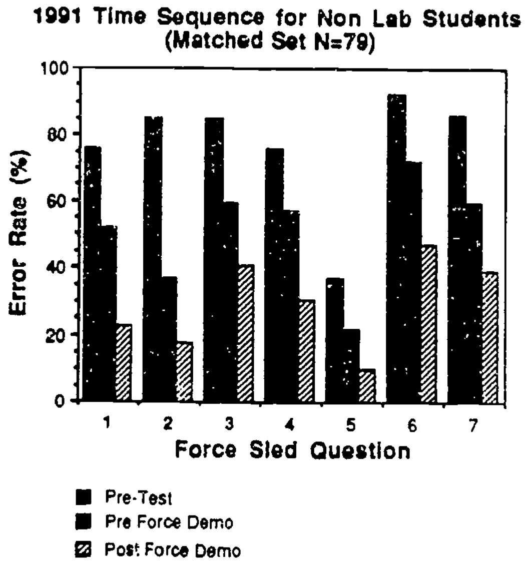


Figure 10. Error rates on *Force Sled* questions for students with lecture instruction only, including interactive lecture demonstrations. The sequence of testing in shown in Figure 8.

Notes and References

1 This work was supported in part by the Fund for Improvement of Post-Secondary Education (FIPSE) of the U.S. Department of Education under the *Tools for Scientific Thinking* and *Interactive Physics* projects, and by the National Science Foundation under the *Student Oriented Science* and *The Workshop Physics Laboratory Featuring Tools for Scientific Thinking* projects at Tufts University, Dickinson College, and University of Oregon.

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Peer Interaction Formats Enhance Problem Solving in Science Classrooms

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Problem-solving skills are essential tools for learning, doing, and teaching science. Most people solve problems in different contexts in everyday life, for example whether to buy a 32- or a 64-oz. bottle of Tide to get the better buy or how to figure out what is wrong when the VCR suddenly stops working. Some important aspects of successful problem solving include (1) thinking about each problem with a flexible and fresh approach and relating what is new to what is already known, (2) assessing if sufficient information is available to solve the problem or how to go about obtaining additional information, and (3) dealing effectively with frustration or any other emotions so that the ability to think is not overwhelmed. In this paper, we review several collaborative formats that we have implemented to enhance problem solving for science students from middle school to college level. While the formats vary, they focus student attention on both cognitive and affective processes in problem solving. We comment on affective processes as they are related to doing cognitive tasks and offer examples of formats we have implemented in our classrooms.

Many current models for science courses at the postsecondary level emphasize mastery of factual content in passive learning contexts such as lectures (AAAS, 1989). Students are often presented with large amounts of material at the expense of opportunities to construct their own conceptual frameworks. This means that they often do not get time to discover for themselves what scientific inquiry involves, to reflect on what they are learning and how they are learning it, or to assess how the facts are relevant to their learning. Where students learn methods for problem solving, these are often goal-oriented at the expense of inquiry-based learning. Finally, in contrast to the extensive collaboration characteristic of modern science, it seems odd that students are still expected to learn in isolation.

In addition, affective processes are almost universally ignored in current classrooms. Yet students are often confronted with emotions and attitudes that arise for them concerning their abilities, concerning science, and concerning learning and classroom issues in general—feelings of boredom, of frustration, of being stupid, of math phobia, and so on. Further, teacher reactions to students' emotional responses in learning situations can make the difference between high achievement and dismal failure in science for minority students (Massey, 1992) and women (Widnall, 1988), as well as other students. Cognition and affect are interactive rather than mutually exclusive functions of intelligence; affect can influence access to cognitive processes (Piaget, 1981). Permitting the expressive aspect of affect in the classroom can remove blocks to flexible thinking by releasing stored emotional tension. Laughing, yawning, sweating (and, more rare in the classroom, shaking or crying) represent physical manifestations of releasing stored emotional tension, so that the ability to think is recovered rather than being overwhelmed by feelings (Jackins, 1964; Weissglass, 1990).

Collaborative learning formats of various kinds (Slavin, et al, 1985; Slavin, 1990; Sharan, 1990; Davidson, 1991) have been widely used in the nation's schools, but not in colleges. Peer interaction enhances science achievement (Slavin, 1990; Sharan, 1990; Light, 1990; Light, 1990/1991) and improves conceptualization where the task

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involves abstraction rather than memorization (Damon and Phelps, 1989). In addition, collaborative learning programs have had a positive impact on the achievement of minority and women students (Treisman, 1985; Webb, 1985; Kagan, 1985; Johnson, Johnson, and Maruyama, 1983). The success of these methods can be attributed to their creation of an environment where students can interact with science and, as importantly, with one another. Collaboration reduces isolation, increases engagement and participation, and encourages students to clarify and articulate their thinking.

We use collaborative formats for problem solving that are designed specifically to address the need for time not only to reflect and interact with the subject, but also to deal with emotional issues that may prevent problem solvers from thinking as clearly as they are able. This is most effectively accomplished in the company of an attentive listener. Consequently, we spend a little time at the beginning of each course training students to become effective peer listeners (Weissglass, 1990; Puttick and Chew, Unpublished; Chew, 1992). In pairs, students learn a few operating rules: (1) to share equal time, (2) to look attentive and approving, (3) not to interrupt, (4) not to give advice, and (5) to keep confidences. Emphasis in the formats is on thinking, not dwelling on feelings, but if the student gets stuck, he or she has the opportunity to deal with the feelings and then move on with the task at hand.

We have implemented three different formats for problem solving in a wide range of courses at the middle school, high school, and college undergraduate level. All three formats provide the chance to go back and forth between thinking and feeling to solve a problem. In practice, the formats require that students learn to listen and pay attention to each other before being asked to use them. With practice, students get better at listening, not interrupting or giving advice, and assisting each other in dealing with feelings. Students usually work in pairs (dyads) to use these formats, but we have also implemented some group adaptations that are mentioned later. The dyad formats are useful for several different types of problem solving. They are particularly useful for solving circumscribed problems. Examples include math problems; statistics problems; quantitative problems in genetics, population biology, etc.; and problems of estimation or of logic. Work in pairs can also be useful for defining more open-ended problems. Examples include developing an argument or searching for evidence to support or refute different hypotheses or interpretations.

Learning to Listen

We practice using dyads in our classes by using several kinds of short exercises that permit student reflection. First, we help students "wake up" (especially useful in early morning or evening classes) by asking them to take one minute each in separate turns answering "What's going well for you?". Each pair decides which student will talk first. The teacher keeps time—a lab timer is useful for this. When the timer goes off, the teacher prompts students to finish their sentences and switch roles. The teacher can participate as a member of a pair if there is an odd number of students. Groups of three also work but make time-keeping trickier. Tardiness has declined in every class where we have used these. When questioned, students say they do not want to miss the dyad.

Second, we can focus student attention on a new topic by enabling them to brainstorm about that topic and share what they already know. For example, at the start of an introductory ecology class, we ask students to recall what associations the word "ecology" brings up for them. Likewise, students can use these "focusing dyads" to review in preparing for further work on a topic. For example, for a discussion of population ecology of different plant groups we might ask students to take one to two minute turns to consider what they know about the factors affecting plant growth requirements. This serves to validate what students already know,

get them thinking about the topic, articulate what they are interested in, and, if thinking is solicited by the teacher afterwards, provides a relevant starting point for the lecture or lab, etc. By taking turns, talkative students learn to listen and to be concise, while "shy" students learn they will have equal uninterrupted time to respond. This practice socializes students to share time more equally when nonstructured brainstorming (see below) is used.

Third, after a lecture segment, film, or presentation (15–45 minutes), we ask students to take two minute turns in pairs to think about what they have just heard, and then we ask for questions and comments after the dyads. We find that student questions are more thoughtful after a chance to reflect on content. For example, questions and comments such as "Would you say that again?" or "I don't understand!" are replaced by specific questions on some aspect of the material.

We find that these three short dyads help to socialize the class into a learning community. Although our evidence is only anecdotal, based on student self-report, we have found that these formats have noticeably increased student engagement with, participation in and enthusiasm for science. We get student feedback like "This class goes by real fast," "I'm learning more in this class than in any other," and "Feelings really *do* affect thinking." Students ask more thoughtful questions and pay better attention after having a chance to reflect on the material. They come to regard their peers as resources rather than focusing on the instructor as the sole source of effective assistance (Puttick and Chew, Unpublished; Chew, 1992). The dyads also help prepare students to listen effectively to their peers in the problem-solving formats described below.

Work Session

This format involves each student working individually on the same or different problem for a set time period (4–10 minutes, depending on the difficulty or complexity of the problem). Then the partners each take a 1–2 minute turn in a dyad to report on their progress or express how they feel or both. Each student then returns to working on his or her problem for an additional 4–10 minutes. The teacher keeps time and reminds students when it is time to switch.

Outside the classroom, students can use an extended version of the Work Session, working for 2–3 hours on problem sets, term papers, or studying for exams. Students work for an agreed-upon length of time, then take 5–10 minutes each to report on progress and feelings and to plan the next steps before resuming work.

Think and Listen

This format involves each student working on her or his problem while the other pays attention. Students each take a turn to think aloud about their problem for 5–10 minutes while the other student listens, pays attention, and takes notes if asked. The thinker uses the time in the way that is most useful to him or her—solving the problem or thinking aloud about what he or she knows about the problem and what is needed to solve it. If the thinker gets stuck, the listener encourages the thinker to express feelings. Short, nonverbal expressions such as gestures or noises are most effective. After a minute or so of nonverbal expression, the listener encourages the thinker to continue thinking aloud. Again, the teacher keeps time and reminds students when it is time to switch.

This format can be most effective with very challenging problems, but only after the class has practiced listening, so that students will be able to listen to each other for 5–10 minutes without interrupting or giving away the solution. Students will be able to build on one another's responses if they start work on the same problem from the same starting point. Alternatively, students still benefit if they work at different paces; each one will get a chance to confront a cognitively challenging situation with encouragement and an immediate chance to express feelings that may arise during the task. "High

achievers" get a chance to learn patience and to let "lower achievers" come to their own conclusions. Since even "very high achievers" may have feelings about cognitively challenging situations, they often find that being listened to by a "lower achiever" provides assistance in problem solving, even though the latter provides no information about solving the problem. This may also be a rewarding experience for the "low achiever." Students have commented, "Two heads are definitely better than one" and "I can think better when I'm talking."

Work Session 2

This format has basically the same structure—students work in pairs and take turns—but here they collaborate together on the same problem. Students work together for a set time period up to about 10 minutes. Then the partners take turns in a dyad to express how they feel for a minute or so. Finally, they return to the problem for a further 10 minutes. This alternating between working together and breaking for dyads can continue for as many repetitions as are required to finish the task. Students may develop their own pattern of time spent in each part of the session—some may find 5 minutes on problem solving all they can handle while others may want to take 20 minutes. Likewise, students may only want to stop for dyads when they find they are stuck or when they notice that their feelings are overwhelming their ability to think clearly about the problem. Whatever timing they adopt, students need reminding that they should each have equal time when they stop for dyads. Students need to keep time for themselves in each pair. Students must work on the same problem simultaneously, and this format usually works best if students have prior practice at taking turns. Otherwise, as pointed out by Damon and Phelps (1989), students may not be mutually engaged.

Brainstorming

All three formats described above can also be effectively used for brainstorming about specified problems or topics. Brainstorming together often generates faster solutions and allows students explicitly to build on each other's thinking. On the other hand, taking turns in dyads will persuade "shy" or "underachieving" students to rely more and more confidently on their own thinking, especially if dyads are used consistently so students practice listening to each other. Having an uninterrupted turn gives them a chance to express some of the feelings and to speak without being interrupted by more vocal or less patient students. The teacher needs to say clearly whether the students should brainstorm together or brainstorm taking equal turns to contribute a thought. Likewise, group brainstorming proceeds with greater participation when students have had prior practice participating in pairs.

Work in Groups

Work sessions, brainstorming sessions, and think-and-listen sessions can also be used in groups of three or four students. (Social dynamics in groups larger than this tend to become unwieldy.) Groups are often suited to studying more complex issues or situations in which there is evidence to support many viewpoints or where there are arguments in favor of differing interpretations.

For example, we have had freshman and sophomore students in an introductory biology course consider the problem of tropical rainforest destruction. Interest groups include bankers, native forest dwellers, cattle ranchers, consumers of fast-food hamburgers, timber companies, etc. Each student group chooses an interest group to represent. They start by brainstorming to identify what they know about that group and what they

need to know about the group or its concerns before they can speak for it. Students then do library research, using the work session format, to get the information they have identified as important. They prepare presentations using the Work Session 2 format. They present short oral presentations collaboratively. After each presentation in class, students take two minutes each in pairs to think about what they have heard and to formulate questions.

Conclusion

Rather than focusing student attention on mastery of factual content, these formats instead enable students to become active architects of their own scientific learning and experience. Their *interaction* with science and with others engaged in the same activity, rather than being *taught* science, is what gives science meaning. With encouragement to build on what they already know, to use diverse skills they have already mastered, to work together, and to deal effectively with their feelings about challenging tasks such as problem solving, science becomes more accessible to students.

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Erasing Paradigms: An Experiment in College Teaching

George P. Moore

It was my great privilege and pleasure to teach a university course a few years ago on research design and methodology. The original intentions of that course were to introduce students to the standard equipment of the discipline, have them read a classic or two from the literature, repeat some aspect of the classic paper, and develop some incremental improvement on it. In other words, the class was intended to be an introduction to the experimental paradigms of the discipline.

For the fun of it, I was persuaded to alter the basic pattern of that class for several years, and I now offer a description of it as an example of an exercise that might serve in the training of science and mathematics teachers.

In what we hoped was innovation, we continued to use the equipment of the discipline—measuring and recording devices, for example—but employed them without a paradigm, as I will now describe. I will give but one example from a single class that is relatively easy to visualize and recall.

The Laboratory Task

On the first morning of the class, which met two entire days a week for six weeks, the students worked in a laboratory equipped with conventional recording devices and a few special pieces of measuring equipment—in this case two accelerometers.

A volunteer was asked to raise his arms and point the tips of both index fingers at each other, separating them by a distance of 1–2 mm. An accelerometer was placed on each hand in such a way that it measured, primarily, the small but incessant accelerations of the finger tips toward or away from each other, that is, primarily in the right/left direction.

We then recorded the two channels of acceleration data on a chart recorder and simultaneously digitized the signals for later computer analysis. Data were obtained during a contrived set of tasks that students performed:

(1) The subject was instructed to attempt to hold the finger tips at a fixed distance of 1–2 mm and to avoid touching them together. No fiducial marker was provided.
(2) The subject was then asked to repeat this with his eyes closed.
(3) The subject next viewed his fingertips through a dissecting microscope with a magnification of 25×, and again was asked to fix and maintain the separation distance.
(4) A video camera was placed facing the subject, and a closeup view of the fingertips was displayed on a color video monitor placed two feet in front of the subject. The finger tips occupied the full screen. The subject was again asked to maintain a fixed separation using the video monitor. No explicit mention was made of the fact that the display reversed right and left. A VCR recorded the images.
(5) The subject next returned to the initial position and was asked to fix the position of the left hand and make adjustments in distance between the fingers by moving only the right hand.

(6) Elastic straps were attached to the thumbs of each hand such that the force of each strap was directed (primarily) to the side, tending to pull the fingers apart. The two straps exerted different forces and had different stiffnesses. The instructions, once again, were to maintain a constant separation of the fingertips.

(7) Finally, one of the accelerometers was removed and placed on the hand of a second subject. The two subjects, facing each other, were then instructed to point their index fingertips at each other and maintain a fixed distance.

The Assignment

At the conclusion of this initial session, the immediate assignment was to inspect the chart recordings and report any interesting findings at the next session.

The students considered the equipment to be straightforward if not familiar, but urgently wanted to know what the subject or object of this study was and where they might read more about it. With no answer forthcoming, their anxiety was acute.

The standing assignment for the remaining class sessions was to identify at least one interesting result, explain why it was interesting, propose several hypotheses that would account for the interesting finding, and design an experiment capable of rejecting at least one of the hypotheses. That was the price of reentry into the laboratory.

Students were encouraged (actually, exhorted) to keep a journal record of their explorations, to document and justify every measurement, and to predict, in advance, the outcome of each measurement. Computer calculations based on the data were executed for them (so they would not have to spend time programming), but they had to be explicit about the details of the requested calculations.

Observations

Invariably, students found the experience exhausting and more than a little frustrating. It was their first experience in having to adapt or actually invent, *de novo*, a paradigm. The feeling of helplessness this created was very painful. For most, it was the first experience in discovering that the pattern of behavior cultivated in their prior educational history was, for our purposes, dysfunctional. They were previously rewarded only for having correct answers, and now risk and error were being stressed as prerequisites for progress and insight.

Generally, students confused observation with hypothesis, data with explanation, and premise with conclusion (confusions that appear surprisingly often in published papers). By design, library work could at best only clarify issues relating to the equipment itself, and they had yet to discover that their ignorance of the design principles of the accelerometer would be almost fatal. Only the brightest would recognize—too late—that our failure to calibrate the accelerometers on the first day was going to cripple much of their work.

Students persisted in calling the first day's activities "experiments," while I insisted on the more neutral term "procedures," from which an experiment might some day evolve.

Later, they would discover that their imperfect understanding of the concept of acceleration itself, and its relation to velocity and position, was a confounding factor. They were to rediscover Newton's Laws and the mathematical process of integration (to say nothing of spectral calculations) as if for the first time. At first, this embarrassed them, in spite of attempts to persuade them that these were genuine, if not novel, intellectual achievements.

Ultimately, each laid claim to some new phenomenon, insight, or truth that had not been "discovered" before; but each would appreciate the cost of that achievement.

For the instructor there were comparable risks and benefits. First, I would gain a much deeper understanding of the subtle strengths and weakness in the intellectual profile of each student than I could possibly hope to achieve in a conventional setting. By the end of our sessions, unique cognitive patterns of each student became manifest, with some students exhibiting rigid commitments to, and others eclectic or imaginative uses of, miniparadigms to which they had been exposed in their prior training. Some had only the flimsiest bases for their work.

I also learned to recognize characteristic defense patterns erected by students against the constant exposure of their intellects. They rarely trusted their data, their observations, or their insights. Many called for repetition of the original procedures, without modification. Others wanted, or demanded, more "accurate" data or more "precise" calculations. The ardent defenses of some students rendered them, in my opinion, unteachable, though I agonized over whether the responsibility for this was theirs or mine.

Indeed, the most puzzling and disturbing aspect of their working style was an unexpectedly high degree of dependency, as if the net result of their very extensive education had been to increase, rather than decrease, their dependency on a teacher or text authority. They did not always act as if the tools bestowed upon them had equipped them for independent work.

I, too, kept a journal of my own observations and experiences, and as I studied the problems and anxieties of the students, I began to recognize my own. The greatest difficulty for me as I struggled with the laboratory observations was the ever-present temptation to act as if I knew already the answers toward which all of us were groping. To act as if I did would confirm and reinforce the false mutual covenant we had shared in earlier classes. And while I was not entirely successful in avoiding the temptation to do this, at least I became acutely aware of the relentless pressure on me to be perceived as competent, respectable, omniscient, and secure.

In truth, my own anxieties were very great. How could I be sure there was something of interest in the laboratory results? Worse, what if the students saw something important that I did not? Or understood something I could not? Or, what if I were just plain wrong about something? How would I face that? How would *they* cope with that? What if the class was boring; meaning, of course, what if *I* were boring?

Relevance to Teacher Training

The experience I have described was intended for graduate students preparing for research careers. But I think the situation in which we found ourselves was comparable in many ways to that of secondary school teachers attempting to teach science to students lacking formal, systematic training in any scientific discipline. That training, while providing the tools for contemporary professional scientific inquiry, greatly restricts the class of admissible questions, relevant knowledge, and methodologies, and hence has as its goal the gradual creation of a style of thinking very different from the style of thinking that might properly be the goal for high school students.

In that respect, a college professor—even one who accepts the responsibility of teaching—may be a relatively poor resource for teachers at earlier levels. For example, few biology professors today will ever have a knowledge of the natural biological world that was common one hundred years ago or any first-hand knowledge of the equipment used in laboratories at that time (which would be relatively inexpensive and often home-made). And yet this knowledge would probably serve high school teachers far better for the tasks they are required to fulfill, especially in dealing with the types of interests and questions most likely to arise in the minds of their students.

The experience I have described might be very useful in preparing high school teachers to understand better the essence of the scientific

experience and the reactions their own students might show in response to it. It would help to expose the shallowness of "science fairs" (a genre of techno-busy-work that NASA space shuttles have raised to new heights) and the charade of the various Science Talent awards.

Our laboratory exercise was the antithesis of those carefully constructed curricula in which each technique, theorem, or principle is neatly—and artificially—coupled to a set of solvable problems; and of laboratory exercises (improperly termed "experiments") carefully planned to provide generally predictable results. These, of course, are indispensable aspects of scientific education, but by design invert, and hence cultivate a misunderstanding of, the scientific experience.

One aspect of the experience I have been describing escaped me at the time. There was an element of playfulness and amateurishness in our laboratory procedures. In contrast, modern college and university science has become a business, with all the connotations that may evoke. As a result, modern professional science, with a few interesting and notable exceptions, has extinguished amateur science. I now regret not having more consciously emphasized the intrinsic value (and enjoyment) of playing with ideas, paradigms, and technology.

Let me make the point another way: I suspect that very few, if any, colleges or universities (or grade schools) make space and equipment freely available to students, for research, play, or adventure. These schools, in my opinion, would be taking their educational role seriously.

Yet we make athletic facilities available for play. To a large extent, musical facilities are available for playing music (especially in the new electronic era), and similarly, computers are available for play and mischief. It is precisely in these three areas that we can look with considerable pride to exceptional creative and technical achievements among younger students. Yet we miss the whole point by disparaging athletics, abolishing music programs, and trying to restrict or punish the activities of nerds. We fail to recognize that play is an indispensable ally of hard work, discipline, and intellectual growth.

Most university space and equipment is committed. Research designs are generally fixed from above. As in most businesses, there is little opportunity for experimentation, risk, or play. If you want to become a professional, there is often no choice but to buy into an existing program, a fixed paradigm—missing an important experience. The "science cartels," including our funding agencies, call the shots. Perhaps this is one of the reasons why so many native-born American students skip graduate school, and why those who remain find the work boring.

During the period I was teaching the course, I often enjoyed stimulating and informative discussions about the laboratory sessions with colleagues from various disciplines. I now regret an opportunity squandered, since it would have been far more useful to assemble a faculty panel to discuss publicly what they had discussed privately with me; to describe the outcomes they expected from the laboratory measurements and attempt to interpret the interesting results that were in fact obtained.

The truth was that although most colleagues confidently predicted the results their predictions were mutually contradictory and rarely correct. There was too much in the situation that could not be anticipated, too many results that, without careful thought and analysis, seemed counter-intuitive. But such a public and voluntary display of informed and disciplined intellectual activity, inevitably associated with misperceptions and ignorance, although painful, might have been liberating and instructive for students, professors, and especially prospective teachers at all levels. But would we, as teachers, have been capable of assuming such public risk?

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Science Exhibitions Promote College and Community Interaction

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ABSTRACT
Science exhibitions presented by college students at local elementary schools foster goodwill in the community, give college students an opportunity to share their science as role models, provide elementary school children with a positive, enjoyable approach to science, and can be organized rather easily following guidelines that outline procedures for all those involved.

Keywords: Education – precollege; education – science.

Introduction

A science exhibition presented by college students at local elementary schools can foster and develop good relations with the local community. This paper describes the procedures necessary to maximize benefits for all involved and provides steps to streamline the process.

The science exhibition has worked well with local elementary schools of several hundred fourth, fifth, and sixth graders. This age-group selection is based on maturity and cognitive level. A two-hour time span, preferably from 10:00 am to noon, seems to be an optimum. At Cypress College we typically have 20-40 college students taking introductory earth-science and geology courses select this option and share their knowledge of the earth as a project or extra-credit activity

The local school benefits from the knowledge gained by their students and the enthusiasm generated by the "big kids" sharing their knowledge. The college students benefit from the teaching experience that puts their new knowledge to work in the real world. Teachers at the elementary school also find the science exhibition to be stimulating and informative.

The college students who elect to participate must prepare a project or display on an approved aspect of earth science or geology that they can present in ten minutes. The projects, set up in the designated classrooms (see Figures 1-4), are presented during the two-hour science exhibition at the elementary school. Space for the projects must be provided in the fourth-, fifth-, and sixth-grade classrooms (preferably two projects per class situated in opposite corners of the room) and in other available and adjacent rooms.

One of the first steps that needs to be taken is to designate a contact person at the elementary school. The contact person can perform important functions, for example, preparing location maps for college students and rotation maps for elementary-school students, locating necessary audio-visual and other equipment, and mediating the needs of teachers, administrators, and participants. College students with siblings or children attending the elementary school, or staff or faculty from the elementary school who happen to be attending your college, tend to be excellent contact people.

The students will need the 30 minutes before the science exhibition commences to set up their stations, and the fourth, fifth, and sixth grade teachers need to know that the students will be arriving and setting up. The ten minutes allotted for the elementary-school children at each station has worked out as a reasonable length of time for the college students to present their material, and groups of ten elementary-school students seem to be manageable by the college students who are not necessarily accustomed to this role. Repeated shifting to new projects creates an atmosphere of excitement among the elementary-school students and acts to hold their attention at each station.

Suggested Projects for College Students

The projects put together by the college students need to be enjoyable, yet informative. Visuals with good explanations always enhance student performance as does provision of something to take home, for example, word searches, rock and mineral specimens, crossword puzzles, fossils, or diagrams. The students can often make use of materials that are available in the geology department at little or no cost.

Following is a list of a few of the many successful projects presented by Cypress College students.

1) Minerals and rocks in everyday use, for example, hematite and a nail, quartz sand and glass, graphite and pencil lead, talc and talcum powder.
2) Fossils: Constructing casts and molds, types of fossils, types of fossil preservation, the ever popular dinosaurs.
3) Local environmental problems: The college students can build models of local problems dealing with groundwater, flooding, erosion, volcanic eruptions, and/or earthquakes to make the elementary students aware of environmental issues.
4) Gold panning: A child's inflatable swimming pool with sand, water from an available faucet, pie pans, and salted pyrite provide a hands-on-approach to gold panning. Ribbons saying "I panned for gold today at ________ Elementary School" have been a big hit (Figure 3).
5) Volcanic eruption: Always a favorite. The school children love erupting volcanoes. This project never grows old. Different types of volcanoes from those that produce lava to those with pyroclastic eruptions are sensational.
6) Maps: Topographic maps, relief maps, bathymetric charts, road maps, geologic maps, different scales of maps.
7) Glaciers: Ice block models with rocks frozen within, slides of glaciers, relationship to sea level, climatic changes, icebergs.
8) Caves: Limestone, reaction with acid, solution experiments, stalagmites and other secondary cave features, sinkholes, and so on (see Figure 4).
9) Plate tectonics: Moving-plate model (with felt parts to allow mobility of plates), jigsaw puzzles, seafloor topography, location and type of earthquakes.

There is no limit to the project ideas that students come up with. Some students need to be given ideas; others, given the license, are absolutely astounding in their creativity.

Figure 1. A college student on the right is demonstrating volcanoes with models she has constructed for the science exhibition. A fourth-grade teacher observes the demonstration along with a group of students. The volcano models were donated to and eagerly received by the elementary school. (Photo by Nancy Miller)

Figure 2. College student, in striped shirt, showing fossils including fossil fish, clams, and snails, and petrified wood to illustrate different types of fossils and their preservation. (Photo by Nancy Miller)

The abbreviated presentations given in the college classroom or during an appointment with the instructor insure that the students are prepared for their science-exhibition

Figure 3. Elementary-school students cluster in the schoolyard around gold miner and small swimming pool filled with water, sand, and pyrite for an explanation of the gold-panning technique while they attempt to pan themselves. (Photo by Nancy Miller)

Figure 4. College students engage elementary students in a question and answer session after they have used visuals to discuss spelunking and cave formation. (Photo by Nancy Miller)

presentations. If a student is not prepared, there is still an opportunity to eliminate him or her from the master list. Such elimination is necessary because the master list is the basis for setting up the rotation plan at the elementary school.

The last steps that must be taken prior to the day of the science exhibition are to:

1) finalize the master list of student projects;
2) prepare a map (for the college students) showing the location of the elementary school and giving the date and time of the exhibition;
3) prepare a plan showing the location of each project at the elementary school and the rotation pattern to be followed by the elementary-school students;
4) give copies of the master list of projects and the plan to the elementary-school principal and each elementary-school teacher; and
5) give copies of the master list, the plan, and the map to each college student participating in the project.

BEST COPY AVAILABLE

1. Are you willing to assist in setting up a science fair at your school? ____________ (The science exhibition requires designating a person to assist in dividing the elementary-school children into groups and establishing a rotation system amongst the projects.)
2. Contact person designated ____________
   His/her telephone number: ____________
3. Can you provide a map of the school layout which would:
   Specify the location of the fourth, fifth, and sixth grade classrooms. ______
   Show the location of outdoor water faucets, ______
   Show the location of outdoor electrical plugs, ______
   Show entrances and exits to facilitate establishing a rotation pattern, ____________
   Show the location of parking, unloading, and reloading sites for college students on the day of the science exhibition? ____________

   Prior to the science exhibition, a plan for the contact person, your staff, and my students will need to be constructed so that, at the designated start time, the elementary-school children, predivided into groups, will have a plan and a leader who understands the rotation pattern at the ten minute audible signal. My students will also need to have their copies of the map so they know where to set up their permanent stations prior to the start of the science exhibition.
4. Number of students in fourth, fifth and sixth grades ______.
5. Is there an audible system for the 10-minute rotation signal ______ (to make certain that all rotations occur concurrently).
6. How many slide and overhead projectors are available for college-student use during the science exhibition? ______
7. Please suggest several feasible dates. ____________ ____________/____________, ______
   (The science exhibition should be held during the latter half of the semester or quarter to insure that the college students receive the maximum benefit from the course they are taking. Please take into consideration the student's schedules when suggesting dates.)
8. What time would you prefer for this two-hour time block for the science exhibition? ____________
   (Ten to noon has proven to be the best because it creates a diversion, commencing after a recess and ending when lunchtime arrives.)

Table 1. Information sheet to be completed by elementary-school principal.

Experience with the Science Exhibition

The science exhibition has become a rather popular activity in our area, and school principals now call asking Cypress College students to present the exhibition at their schools. To insure the interest of the elementary school, and to encourage the college students and to give them an immediate reward when the event is over, I ask the principal to arrange for the local PTA to provide pizza for the college students afterwards. The cost of this gesture of goodwill is nominal, but the occasion provides an opportunity for review and release of emotion for a project well done.

The science exhibition has never failed to develop new appreciation by the college students of what is involved in teaching and has also brought Cypress College to the attention of the local community. I invite anyone interested in conducting such a exhibition to contact me by letter, telephone call or FAX.

Project Interest Sheet

Due ____________

Project Title ____________

Your Name ____________ Partners ____________

Projects are limited to one or two students per project. Your size and space requirements for project presentation is the constraint. Both students are responsible for the success of their project. [Not limiting the presenters to one will give some students the courage to select this project option, drawing on different strengths.]

1) Short paragraph describing the project idea.

2) An outline of the project:

3) List of visuals that would be prepared for project:

4) List of audio-visual equipment needed for your project:

5) Help! I would like to participate, but don't have a clue about how to go about organizing such a project. I would like to make an appointment to discuss this subject ____________

You will be required to give an abbreviated version of your project either to the class the week before the science fair or to me in my office.

Project accepted ____________
Project accepted with modifications or suggestions
____
____

Project rejected because
____
____
____

Table 2. Form to be completed by college students.

About the Author

Dorothy LaLonde Stout is currently president of the National Association of Geology Teachers and has utilized the science exhibitions throughout her teaching career as a method of involving her college students in increasing community appreciation of science.

Collaborative Learning as an Instructional Innovation

Sarah B. Berenson, North Carolina State University

Tell me, and I'll forget
Show me, and I'll remember
Involve me, and I'll learn

—Chinese Proverb

Rationale

Current reforms in mathematics and science education address the need to change K–16 mathematics and science content and pedagogy. The problem that these reforms address is that of preparing students, teachers, and undergraduates who will be mathematically, scientifically, and technically prepared to contribute to the work force of the next century. The success of these reforms rests in large part with the changes that teachers and university faculty are willing and able to make to their own teaching. The Mathematical Sciences Education Board (1989, 1991) advised in its action plans that university faculty lecture less and try other teaching methods. However, most teachers and faculty have not learned or taught in this proposed environment.

The National Council of Teachers of Mathematics (1991) and the Mathematical Sciences Education Board (1991) are concerned with personal experiences for prospective teachers that model and promote alternatives to the lecture method. One assumption of the *Professional Teaching Standards* is that *teachers are influenced by the teaching they see and experience* (National Council of Teachers of Mathematics. 1991, p. 124). From kindergarten through graduate school, these experiences are used to construct teachers' belief systems about what and how to teach mathematics. Shymansky and Kyle (1992) stated that science teachers believe that they are constrained to teach by lecture, and that these beliefs prevent the implementation of the proposed reforms that reflect a constructivist curriculum.

Collaboration and Active Learning

Advances in cognitive psychology have revealed the importance of the active involvement of learners in experiences that link previous learning to new learning. Collaborative learning is one way of involving undergraduates in active learning within the classroom community and may be loosely described as any activity that involves students, faculty, and administrators in groups of two or more and requires the cooperation of the members of the group to complete an inquiry activity. Social cognition is the theoretical framework for collaborative learning.

Social cognition emerged as a field of developmental psychology in the late 1960's and was strongly influenced by Piaget's cognitive theories (Overton, 1983). One interpretation of social cognition is that it is the process by which individuals grasp one another's meaning during communication (Damon, 1983; Wertsch, 1991). Cognitive psychologists, including Bearison (1982), Damon (1983), and Vygotsky (1978) contended that peer interactions facilitate an individual's construction of new knowledge or the transformation of old knowledge. "Socio-cognitive conflicts" (Mugny and Doise, 1978) create disequilibrium for the learner (Damon, 1983) and provide opportunities to correct misconceptions, fill in knowledge gaps, discover

discrepancies, and reconcile conflicts of perceptions among group members.

- Collaborative Learning Activities

Study groups. Rather than rely on students forming their own study groups, lecturers can create and meet with each group early in the semester to get the groups started. Some instructors give additional credit if study groups meet with the instructor or a teaching assistant for a specified amount of time over the semester. Other instructors set up electronic bulletin boards for student study groups.

While classroom quizzes, tests, and exams foster individual competitiveness, study groups can provide a context of cooperation among small groups or teams of students. One instructional approach is to give each member of the group a different portion of a study guide for which he or she is responsible to the group. Additional incentives to work together can be given, such as adding bonus points to an individual's grade if every member of the group scores above a certain standard on the assessment.

Reciprocal peer questioning. Another collaborative learning strategy is reciprocal peer questioning. Individually, students generate a list of task-specific questions related to classroom lectures from a list of generic questions. Examples of these generic questions or questioning stems are: What happens if ....?, Explain why ....?, How are .... and .... similar? (King, 1990). Then in small, collaborative groups, students take turns posing questions to one another and answering each other's questions.

Collaborative lectures. For large lectures, the instructor may organize classes around a series of questions to which students must respond. Questions can be distributed in the previous lecture or at the beginning of the current lecture. Sometimes, lecturers require the small groups to pass in written answers to the discussion questions. Since a lecture class of 300 will have as many as 60 groups, some instructors tell students in advance that they will grade only 10% of their written answers. Another strategy is to lecture for 10 minutes and allow students 2 minutes to discuss the main idea of that 10-minute presentation with their neighbors.

Problem-centered small groups. Generally, thought-provoking topics are introduced as questions for student investigations in small groups for the day's class or for a week's assignment. Foster (1989) described an inquiry-based, laboratory approach where his students worked in groups, often having to share their data with other student groups so that a complete answer could be obtained from the different investigations.

Another strategy is to assign a paper, problem, or investigation to a small group of students a week in advance of a presentation to the whole class. All students obtain copies of the group's work before class so that they are prepared to ask questions of the group during the presentation.

Cooperative learning. In cooperative learning, **mixed ability** groups of four to six students work together to complete a worksheet, assignment, or project. This method stresses the group responsibility that all members of the group participate fully to learn. Cooperation and leadership skills are taught directly and indirectly in this context, and members of each cooperative group are assigned a role such as leader, recorder, and questioner (Johnson & Johnson, 1987). Groups rather than individuals are rewarded to motivate students to work together (Slavin, 1986).

Instructor's Role

A set of the instructor's rules, including expectations for group work and grading policies, are given to students before beginning collaborative learning. Group members may be assigned

homogeneously or heterogeneously on a number of criteria (i.e., gender, race, and major), or students may be allowed to form their own groups. The arrangement of furniture should allow students to listen and make eye contact with all group members. The instructor provides guidance and support to each small group, circulating around the room, making observations, giving hints, and clarifying ideas. There is also time for the instructor to listen to ideas and concepts that students have previously constructed that may impede their conceptual development. In whole class discussion or small group reporting, the instructor serves as moderator to clarify and summarize the results of the inquiry.

Collaborative learning is not without problems. Some students prefer to work individually rather than with others. For these students, group social skills may be as important to learn as new content knowledge. A few students will let other students take on the burden of the work and make few contributions to the final product. Some students will try to control the group by taking over. There are several ways that an instructor can encourage full and cooperative participation. At the conclusion of a collaborative project, individuals can provide written ratings of other member's participation (i.e., good participant, shared leadership, accepted others' ideas in the group, and would work with this person again). Selecting a member of the group, at random, to explain the group's ideas is another way of monitoring how well the group met the criteria of collaborative learning.

Summary

Collaborative learning is one of many active learning strategies that can be used as an alternative to the lecture method. Undergraduates can be actively involved on an individual basis, as well as with others. Experts recognize that *group learning can be effective in certain situations and for certain groups of learners* (Linn, 1992, p. 832). However, group process skills are important beyond the classroom and in the workplace of the twenty-first century.

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Holding Office Hours by Computer

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Lecture is but one way to impart knowledge to our students. It is an efficient method because it allows for one instructor to be in the presence of many students at the same time, giving them consistent information with which to work. But in a class so large it exceeds the ability of the instructor to interact personally with each student, the student–teacher relationship changes. The teacher becomes a motivator in a setting that is more theatrical, but is less able to provide for each student what he or she needs individually in order to learn best the material. Teaching assistants must then come to play an important role in instruction, and, in some cases, they become the primary source of instruction to those students who are unable to learn well except in close, nurturing environments. For the pertinent research on how class size affects course outcomes and learning, I would refer the reader to the comprehensive list found in Wilbert McKeachie's (1986) book, *Teaching Tips* (p. 186). Briefly stated, numerous studies have found a small, but significant, difference between the retention of information, the problem solving abilities, and the attitudes toward instruction of those students in large and small classes. As one might expect, longer retention, better problem solving skills, and more positive attitudes were found in smaller classes. Since science faculty members constantly find themselves battling poor attitudes about their field and facing difficulties with pupils' problem-solving skills, an obvious solution would be to reduce the size of classes we teach, optimally to fewer than 50 per class, which is something many students and faculty alike would appreciate. But the reality of the situation is that in the setting of large, comprehensive universities, big lectures and TA-led laboratories and recitations are a fact of life. If the information flow in education were one-way, from instructor to student, the class size should not have such an effect, for as long as the student can hear and see the professor, teaching

would take place. But education is participatory, and the engaged mind is one open to learning.

Kenneth Eble (1988), in his book *The Craft of Teaching*, lists some general characteristics of a bad lecture (p. 79). Two of these are:

- lack of contact with audience, and
- no references to present context or broader subjects.

The lack of contact with the audience is a frequent complaint of students, yet often faculty attempts to increase that contact are met with resistance and apathy, particularly when the increase is directed toward placing material in context, or enriching the course content. Sheila Tobias (1990), in her book *They're not Dumb, They're Different*, clearly states many of the complaints and characteristics of large science classes. Students feel anonymous and isolated from the instructor and course material. They feel disconnected from the process of education in such a way that we seem to be encouraging their passivity.

The UCSD Perspective

General chemistry classes at UCSD are large. The year-long sequence for science majors (Chem 6ABC) averages 2,000 students per year, and each lecture contains 300–375 students. All these students will have three hours of lecture per week and one hour of recitation–discussion section led by a teaching assistant. Large classes are here to stay, and we need to find ways to work with them that are beneficial to the students, preferably in ways that address the drawbacks of the standard large class. At UCSD, innovation in dealing effectively with these large classes takes many forms—some more radical than others. Some require a bigger change and investment of faculty time than others. A list of some of these methods follows. Note that most of them deal with changes made outside the lecture hall, rather than changes to the lecture itself.

- Faculty holding special problem-solving sessions outside of lecture time
- Faculty teaching one of their own recitation/discussion sections in order to learn first-hand what the TA's contend with in section and see what was misunderstood from lecture
- Faculty and TA's holding office hours by computer
- Faculty holding office hours in the campus cafeteria or coffee shop
- Providing something innovative or "extra" in the discussion section
- Improving the training of the TA's, who have an important role to play in the large lecture setting
- Small group work within the confines of a large lecture hall

I would like to describe in more detail one of these methods and what has been learned from it.

The Chem 6A Experiment: Office Hours by Computer

My office hours, and those of the TA's, are usually poorly attended and inefficiently used. Few students, particularly freshmen, are brave enough to climb the stairs to the office of a faculty member and expose their need for help in an introductory course. Often my scheduled office hours do not overlap with the times that students have free or have chemistry on their minds. Even if students are not intimidated by attending faculty office hours, questions may go unanswered simply because they do not arise during the three hours I set aside for them. No matter how much they are encouraged and enticed to attend them, my office hours rarely have attracted more than about 20 different students (out of 350) over the 10-week quarter. To counter this, some of my faculty colleagues have a 2–3-hour problem-solving session in a classroom instead. This brings in 50–70 students, but the opportunity for one-on-one contact is not

present. Common questions get answered in this forum, but the questions peculiar to each student may still go unaddressed. As one response, I have instituted a question box that I carry to class. I encourage students to jot down their queries or sources of confusion at any time and drop them in. Then I will address the topic(s) in the subsequent lecture. This has been moderately successful, and I continue to use the box, but in the fall of 1991 I tried a more drastic experiment that went beyond an incremental adjustment or change. I replaced most of my face-to-face office hours with computer office hours. Every student in my class was provided with an account on a campus computer that was also on the campus network. The computer is a Solbourne 5/804, running a Unix operating system. My office and home were already equipped with terminals that I used routinely for department, campus, and Internet communications.

Using a technician provided by UCSD's Instructional Computing Center, my TA's and I offered hands-on training sessions to teach the students how to login to the system; read and send e-mail; and read, make, copy, or print a file, etc. I then held office hours in the following way. Students were encouraged to send specific questions to me or the TA's by e-mail. Each student received a personal reply, usually within an hour or two. Then both the question and the answer were put into a file that all students could access and read. I announced that I would login every evening between 10 p.m. and midnight, during which time they would get an immediate e-mail response to a query. Or they could conduct a real-time "talk" session with me on the computer. Questions sent at other times would be answered as soon as it could be managed, usually within a few hours.

I also posted group access files containing announcements about the class, the answer keys to homework assignments, quizzes, and exams, as well as exam scores (listed by SSN with the students' permission).

The computer monitored all logins and session times so I could see the frequency of use. There were 4,600 logins during the 10-week quarter. Of those students who completed the course (310), 112 students used the computer for Chem 6A work regularly (meaning more than 10 times), 103 used it occasionally, and 99 students did not use it at all. Students who had previously used a Macintosh or PC had little advantage over the students who were not familiar with computers at all. All of them needed some introductory coaching, which was a leveler of abilities. Few, if any, previously had access to Internet and all its resources. Over the course of the quarter, I received hundreds of e-mail messages from students, all of which were answered promptly, even if I was at home or traveling. Students did not need to schedule their questions around my office hours, but could send me e-mail when they were studying, which was often in the middle of the night in one of the ICC terminal rooms available 24 hours per day, at various campus locations.

I had anticipated the following benefits from holding office hours by computer:

- Scheduling conflicts between my office hours and the students' free time would be avoided.
- The computer communication would be less personal, but more thorough.
- I might make contact with some heretofore unknown students who needed help.
- This was just one more way to try "hooking" students on science.
- Some would learn to send e-mail to friends and family members at other universities.
- Some would enjoy yet another vehicle for gathering information about the class.

Student response was overwhelmingly positive, for some different reasons than I had envisioned. Some of the things I learned are that:

- All students, but particularly freshmen, felt that gaining access to a campus computer made them a part of the university community. This was what they thought of as a benefit of coming to a big name school.
- Morale was affected, strongly on the positive side. Students thought this method of communication was an indication that I cared about them and the class.
- Students felt the attention they received from me via e-mail was *more* personalized than a visit to my office, because I took the time to compose my response just for them.
- Students gave more thought to the questions they asked than if they had asked them verbally. The act of forming their query for me to read and understand made them compose their thoughts carefully. They spent more time forming the questions, and therefore answered some of them for themselves in the process. Also, they asked more insightful questions than I had encountered in past quarters of teaching this class.
- I had extended contact with many shy students, whom I would never have seen in office hours, particularly those from other countries where they were taught it is disrespectful to question a teacher and it is uncommon to openly admit one needs assistance. These students praised the computer for being able to maintain their dignity while being able to admit they needed some help.
- Most students who communicated with me in this fashion did their serious studying between the hours of 10 p.m and 3 a.m. Obviously these times do not coincide with those when most faculty members and TA's currently hold office hours.

In summary, this was the most successful classroom experiment I have ever carried out. It involved little change in my teaching style but had a sizeable effect on the class morale. It was an efficient use of my time and that of the TA's. I spent an average of five hours per week sorting and answering e-mail and cleaning up files. The TA's each spent no more than three hours per week dealing with the same. The TA's maintained several "normal" office hours each week, and I also was available to students for personal consultation two hours per week, but that time was used by students with private matters to be discussed.

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Science Teachers as Co-Learners

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The conduct of science is dynamic, and the product of scientific enterprise is an ever-changing body of knowledge. Inherent in the scientific method is the continual testing of hypotheses toward (in)validation of ideas that are found to be (in)consistent or (in)compatible with known databases. Uncertainties in scientific investigations are compounded when multidisciplinary approaches are applied; apparent internal consistencies within subdisciplines are often exposed as merely convenient constructs when held up to scrutiny through the filters of related fields. If science advances through questioning, testing, acquisition of new evidence, and formulation of

hypotheses with predictive capabilities, in accord with the "Science for All Americans" (AAAS, 1989) report, why not teach science in the same manner that it is practiced? This approach to teaching science mandates that neither teacher nor textbook may claim absolute authority over the dispensation of knowledge. The science teacher must then assume the role of co-learner with the students to validate available information and to seek new and creative ways to acquire and integrate new observations and data.

I maintain that it is the responsibility of the science teacher to accept (and even introduce) a measure of risk into the instructional method by openly engaging that which is unknown. The relatively safe approach of presentation of prescriptive bodies of knowledge (taxonomies, simple models of relations, overdependence on description, etc.) does not serve to demonstrate the scientific method, and it certainly does little to stimulate interest on the part of the students. However, inquiry-based instruction is an ideal mechanism to simulate the workings of the scientific method. Whether class activities are designed to be "open-ended" (e.g., Moore, this volume), or "guided" (e.g., Sokoloff, this volume), there is a risk that uncertain, unknown, or unpredictable results may be obtained. In this uncertainty there is opportunity. It should be the ole of the science teacher to say, "I don't know how or why this happened, but let's find out!" The wonder of discovery, and the excitement of the search for explanations through application of the scientific method, are the lessons that should be most valued. These are the thinking skills required of students that transcend disciplinary boundaries and which provide the foundation for life-long learning beyond the classroom. The goals of the teacher as co-learner should be (1) to teach by example; (2) to ask questions, formulate hypotheses, design experiments, and try and sometimes fail in obtaining positive results, in demonstrating the process of scientific investigation; and (3) to foster a learning environment that emphasizes the critical thinking skills rather than rote memorization.

If teachers are to serve as scientific mentors by exposing themselves to unknown phenomena in shared learning experiences, they will need to be introduced to these techniques in their initial training. Through practice and experience they will need to become comfortable with the idea that it is acceptable to not know all the answers; they will also have to become comfortable with the pursuit, acquisition, and evaluation of new information toward solutions of classroom problems; they will need to be given the investigative skills to seek answers from a variety of sources. Changes in the pedagogic methods of introductory science courses at the undergraduate level toward inquiry-based and experiential science education is important for all students, but is especially important for preprofessional science teachers, because teachers tend to teach as they were taught. These methods may be further reinforced in special courses designed specifically for teachers-in-training (e.g., Billstein, this volume).

It is not sufficient to train teachers in this new pedagogy and turn them out into the classroom without sufficient continuing support. Systemic support networks of information and materials must be established if inquiry-based instruction is to be transferred to classrooms in the elementary, middle, and high schools. If teachers in the classroom are encouraged to risk venturing into the unknown in the course of their instructional activities, they must be assured that they will have the means to satisfy their questions through some network of external support. This is one area where science faculty can make a continuing contribution: making themselves available for consultations and guest lectures, leading field trips, providing sample materials and demonstrations, and simply being available to answer questions on a routine basis. System-wide communication networks can easily be established between teachers at different schools and with faculty at colleges and universities to provide the necessary support for this teaching method.

It is recognized that there will be resistance on the part of some students to initially accept this mode of instruction. It is far easier for most students (and indeed teachers) to rely upon vocabulary lists, simplified cartoons, and "cookbook" solutions in the guise of science education. However, there is a significant population of students who are already predisposed to this form of instruction; the challenge of inquiry-based education may well fuel their enthusiasm for science as we attempt to repopulate our diminished ranks of science majors. With appropriate incentives, many of these students may well answer the call to become science teachers at various levels. Students, in general, will ultimately benefit from this approach if they at least develop an appreciation for the scientific method and the limits of certainty of our knowledge base. Our campus has successfully implemented a "writing-across-the-curriculum" program over the past couple of years; dedication of the university to this program outlasted the resistance of established students and now it is an expectation that there will be a writing component in all "core" classes. There is a nascent "numeracy-across-the-curriculum" program being formulated, and there could just as well be a "critical-thinking-across-the-curriculum" program. It would probably be a mistake to immerse an uninitiated student body into the proposed teaching–learning environment without some preparation. Judicious use of exercises that include teachers acting as co-learners can be periodically interspersed with more traditional teaching methods to make students and teachers more comfortable with their shared roles as investigators.

Encouraging science teachers to assume the role of co-learners is consistent with topics covered by many of the panels at this workshop:

Collaborative learning. Teachers may participate in small work groups to solve problems with the students; by asking questions, proposing experiments, exploring additional sources of information with the students, the teacher demonstrates his or her role as a co-learner by example. A willingness on the part of the teacher to consider the merit of students' ideas in an open dialogue, and to learn from and react to the students' input, helps to develop the confidence and self-esteem of the students.

Assessment. If the goal is to assess a student's level of learning, it is perhaps more important to develop ways to assess the process of discovery, rather than mastery of a prescribed "right" answer. In this context, the compilation of a journal, records of experiments and results, or on a larger scale a portfolio of varied activities, are better measures of a student's progress in learning (as opposed to memorization). This requires a great deal of flexibility and judgment on the part of the teacher (as co-learner), but again, the lessons learned from a failed experiment are perhaps of greater value than reproduction of a litany of unrelated facts.

Multidisciplinary activities. In a given course of study, certain questions may direct continuing inquiry into other disciplines; the teacher–learner will have to be willing to accommodate information derived from outside the immediate field of study. In addition, multidisciplinary approaches to a subject are a great way to make connections to cognate subjects (e.g., mathematics) and to disciplines outside the sciences (economics, public health, etc.) that affect our daily lives. A teacher as co-learner should have the confidence to look for answers, applications, and implications beyond the confines of a narrowly defined discipline.

Diversity in the classroom. Emphasized at this workshop is the concept that diversity is not an obstacle, but rather an opportunity (e.g., Howard, this volume). There are rich opportunities for the teacher–learner to utilize the diversity of socialization, experience, and ways of knowing that would typically be represented by a spectrum of students in the classroom. There is not a

single valid way of knowing about and relating to the universe; acceptance of alternative approaches to problem solving not only serves to reenfranchise students from backgrounds typically underrepresented in the sciences, but will also enrich the educational experience of the other students and teachers in the classroom. Science teachers would do well to learn from, as well as with, their students.

It is worth the risk for science teachers to eschew authoritarian roles in the classroom and to demonstrate the conduct of science through their own actions. It is a good thing for students to witness their instructors involved with the question-asking and problem-solving methods required for understanding both the conduct and products of scientific investigation.

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Valuing Diversity in the Educational Process

Craig E. Nelson, Indiana University at Bloomington, Chair

Panel Members: Phillip R. Certain (University of Wisconsin—Madison), Frank Collea (California State University, Long Beach), Ruth Doell (San Francisco State University), Jim Henkelman (University of Maryland at College Park), Bess C. Howard (University of Maryland at College Park), Gretchen Kalonji (University of Washington), Adrienne W. Kozlowski (Central Connecticut State University), R. Heather Macdonald (College of William and Mary), Khin Maung (Hampton University), James Nelson, Jr. (Virginia State University), Richard Phillips (Michigan State University), Alvin Siger (Crenshaw High School, Los Angeles)

Discussion and Synthesis

1. We commend NSF for taking diversity ever more seriously. NSF has focused for some time on the disparities among demographic subgroups in rates of recruitment and retention in science, mathematics, and engineering. The inclusion of diversity as a major focus in this conference emphasizes the importance of the way diversity is addressed by faculty in all college courses.

The way we teach is important in the recruitment and training of teachers. It also strongly influences the diversity and number of students that we recruit into the professional and academic specialties in our disciplines. The way we address diversity has thus become of central importance to the academic enterprise.

2. "Valuing Diversity" applies to student heterogeneity generally, not just to demographic subgroups. Effective teaching at all levels must take account of the heterogeneity among students that affect their performance in and satisfaction with our courses. To do otherwise is to overlook the increasing knowledge of how diversity can become a resource and, thereby, to mistake the way we were taught or the way we have been teaching for the way our disciplines should be taught. The importance of the work by Treisman and his associates in teaching calculus is its demonstration that a remarkable enhancement of the achievement by diverse students can be made without lowering the standards of the course (e.g., Fullilove and Treisman, 1990). Hence, it is reasonable to seek ways to achieve "success for all students" (a goal that underlies the program described in the paper by Howard and Henkelman).

Student performance and satisfaction is influenced by several groups of factors including

intellectual development; learning styles and teaching styles; preparation in both disciplinary background and general educational skills; experiential diversity (personal and among-group heterogeneity in experiences, metaphors, communication styles, etc.) and by the students' own goals and aspirations. Developing and implementing ways to address these differences efficiently and expeditiously must be given high priority if science, mathematics, and engineering are to thrive.

3. Diversity is a resource, not a problem. In order to utilize diversity as a resource, we need to come to grips with the unintended biases, hierarchies, and idealogies that are implicit (and, sadly, sometimes explicit) in our teaching. The problem is that faculty unintentionally teach in ways that act to exclude from our fields many students who are able, willing, and ready to thrive in them. Succinctly, the problem lies in teaching, not in diversity. Nelson's paper suggests that nearly every college course is currently taught in ways that unnecessarily reduce the diversity of the students who thrive in our disciplines and are recruited into them. Among the aspects that he suggests that we review and consider modifying are language (images, examples, and metaphors); teacher–student and student–student interactions; inclusivity of content and visibility of heterogeneity; extent to which historical and current patterns of de facto discrimination are discussed; ratio of passive to active learning activities; emphasis on facts and lower-level concepts relative to that on understanding the fundamental nature and processes of science, our disciplinary frameworks, critical thinking, and synthesis and application skills; extent to which we make the ideology reflected in our choices of content and teaching methods visible to our students (and to ourselves); and social class biases and other biases built into our grading schemes. In her paper, Doell illustrates how careful analysis of a discipline can reveal the ways in which both the discipline itself and the ways in which we teach the discipline contribute unjustifiably to current social hierarchies. The extensive feminist critique of science has provided many examples from a variety of scientific and science-based disciplines (see the bibliography in Nelson's paper for selected sources). The growing understanding of the ways in which course content and teaching procedures unintentionally contribute to the perpetuation of bias must deeply enter our own individual agendas for our continuing professional development as teachers.

4. The use of a heterogenous mix of teaching strategies is the key to valuing diversity in classes at all levels. As Howard and Henkelman emphasize, students preparing to be teachers must build a repertoire of teaching strategies. Indeed, this point is a central theme in each of the papers from this panel. Each of the papers also supports, or is deeply compatible with, the idea that this preparation can be done most effectively when the disciplinary faculty model a wide variety of teaching and strategies for the teachers.

Modeling a wide variety of assessment strategies is of equal importance. Kalonji's presentation included an interesting discussion of the use of portfolios in the assessment of a large class.

The use of heterogeneous teaching and assessment strategies is also quite important for addressing the diversity of students in our classes who do not plan to become teachers. Whatever the students' career aspirations, heterogeneous teaching will better accommodate diverse ways of learning and excelling, foster greater success by all students, and help students develop both a deeper understanding and appreciation of the discipline and an appropriate sense of competence. Further, strategies that enable diverse students to excel will thereby foster an appreciation of diversity among students. This is of central importance both for prospective teachers and for citizens generally.

5. Many of the most important additions to teaching repertoires at all levels act to shift the classroom away from an overwhelming emphasis on passive involvement (listening to lectures, taking notes) toward much more active involvement. Central here is the development of collabo-

rative student learning groups and communities. These range from simple pairing for three-minute discussions to the formation of term- or year-long project teams.

Each of our papers illustrates or advocates a shift to more active modes of learning. Macdonald's paper illustrates the power of small-group activities, extracurricular team projects, and peer-discussed writing. Doell emphasizes the importance of discussions, especially those that draw on the student's relevant experiences. Siger's paper illustrates the differences between typical laboratory demonstrations and those which actively engage the student's minds and prepare them for active discussion. He cites explosions, toys, homemade apparatuses, and discordant events as examples of the kinds of activities that the students will remember and actively discuss. The project that Howard and Henkelman describe begins with prospective teachers who are actively engaged as instructional assistants and teacher interns and provides them with opportunities to learn collaboratively as they become licensed teachers. Each paper also emphasizes the use of a more heterogeneous mix of teaching strategies.

The panel's discussion brought out an additional common theme uniting our approaches: when there is a sense of joy toward teaching and learning in the classroom, learning will be enhanced for all groups of students.

6. We need to prioritize traditional content by setting it into larger contexts, contexts that focus on major theories, critical thinking, valuing and social issues, and connections with the students' own interests and lives. Kalonji's paper provides an example of the some processes that can be used in prioritizing the content of a large introductory course. The question here is not one of content versus processes or student-centered teaching (Nelson, 1989). The question rather is how much content is optimal for our goals. When too much content is presented, it interferes with the learning of content, to say nothing of comprehension, synthesis, and application. Students are forced, as many of us will remember, into short-term memorization strategies that virtually guarantee minimal comprehension and retention. Further, such content glutting selects for a narrow range of student diversity and discourages students from nondominant backgrounds without producing any demonstrated increase in the knowledge retained by the students who "do well" using temporary memorization strategies.

7. It is essential but not sufficient for disciplinary faculty to use diverse teaching strategies and otherwise value diversity in the courses they teach. It is also essential to involve them more deeply in explicit, subject-matter-specific, teacher training in ways that range from the sharing of specific, pedagogically powerful activities (such as those illustrated here by Siger) through the processes of identifying major themes, prioritizing content, and teaching activities and planning particular teaching units to strategies for finding or developing appropriate resources and making connections with discipline-based information networks.

8. Too often, perhaps typically, when faculty decide to "do something about" diversity, or other aspects of teaching and curriculum, they proceed on the basis only of what they and their colleagues know. Yet, there is an immense and very helpful body of literature now available on teaching. In the program they describe, Howard and Henkelman emphasize the importance of training teachers to utilize the available research on teaching. To facilitate access by disciplinary faculty to the available literature on training teachers to address and utilize diversity, Howard and Henkelman have included an annotated bibliography. Nelson's paper here includes an extensive bibliography of scholarship that addresses diversity, especially as it relates to college teaching. Menges and Mathias (1988) provide an annotated bibliography of nearly 700 key studies relevant to college and university teaching. They mark 60 of these as "seminal" contributions.

Any rapid increase in our effectiveness in improving scientific literacy and in recruiting

and training teachers, mathematicians, scientists, and engineers will require that all faculty begin to take the scholarship of teaching seriously. Nowhere is this more important than in our efforts to value diversity and to make "success for every student" more nearly a reality. The resources summarized in these bibliographies provide the theoretical frameworks and practical examples that will enable us to make rapid advances. And the tenor of the times requires an increasingly effective approach to teaching.

9. The major problems that must be addressed in educating future teachers are largely identical with the problems in educating college faculty to assume more effective approaches to teaching. Central in both cases is an appreciation of the implications of an increasingly diverse student population for learning and the development of an effective repertoire of teaching strategies. To achieve this, we need to build professional development as teachers into our expectations and reward systems and to provide the time and funding for both professional development and course development.

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Curricular Design for Diversity: A Set of Activities Around the Broad Theme of Symmetry

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Introduction

Our goal in this paper is to share some curricular strategies which we have found useful in encouraging diversity to flourish in an engineering classroom. From the beginning we should stress that we interpret diversity in a very broad sense, as encompassing not only ethnic, racial, and gender differences, but diversity in learning styles, experience, and aspirations. Our strategies are based on the principal that, as faculty, we must mirror in our practice the type of diversity we hope to encourage others to value. While this principle holds true for the general student, it is particularly relevant when we consider the needs of future teachers in our classrooms. In curricular design, we have to consciously work to provide a wide variety of paths to mastery of our disciplines, so that all of our students can contribute to the intellectual health of our communities. The activities we will describe below were created within the framework of a new introductory materials science course at the University of Washington, a course which differs radically from traditional versions in both content and pedagogy (Kalonji, January 1992). Materials science, being intrinsically one of the most interdisciplinary of fields, has multiple, vivid links to other branches of science and engineering. Though few prospective high school teachers currently take our course, materials science would be an excellent discipline, because of its centrality to both science and engineering, for future teachers to be trained in. At any rate,

the strategies we describe in our paper have broad applicability to other courses in engineering and the physical sciences. Certainly, the specific symmetry activities we describe could be placed in a wide variety of settings. We believe, furthermore, that certain aspects of the overall approach will prove of quite general validity in any widespread curricular reform process.

The Structure of our New Materials Science Course

Our new introductory materials science course was developed under the aegis of the ECSEL program at the University of Washington. ECSEL, the Engineering Coalition of Schools for Excellence and Leadership, is a coalition of seven universities that has been funded by the National Science Foundation to undertake a twofold mission:

(1) to improve the quality of the engineering undergraduate experience dramatically,
(2) to enhance the participation of women and underrepresented minorities significantly.

The other schools in the ECSEL coalition are Howard University, Morgan State University, The City College of New York, the Massachusetts Institute of Technology, Pennsylvania State University, and the University of Maryland. A major theme of the ECSEL coalition is the infusion of design experiences throughout the educational pathway of the student. One of the primary ECSEL activities at the University of Washington has been a re-evaluation of the so-called engineering "core" courses, i.e., that set of courses required by many departments and commonly taken by students in their freshman or sophomore years, prior to acceptance into one of the engineering departments. We have taken this opportunity not only to re-examine what we are teaching, but to explore new teaching and learning environments. Explicit in our design criteria has been the paramount importance of creating environments which are "friendly" to diversity. Our course is a "service course" for the majority of departments in our College of Engineering, as well as the gateway to our field for materials science majors. For our materials science course, we have attempted to offer students a multivaried set of pathways to understanding its basic concepts, pathways which differ markedly both in style and in the past experience and future goals to which they are best suited.

The structural changes in our course have been major. The format of the course moved from the traditional engineering emphasis on lectures, problem sets, and exams, to a very heavy emphasis on student-initiated projects and research, undertaken both individually and in large and small groups. The course also stresses the development of experience in oral and written presentation skills. In order to allow such an innovative exploratory classroom environment to flourish, we found it necessary to change our grading strategies dramatically as well. We developed a journal-based assessment technique, which simultaneously offers many educational and social advantages (Kalonji, November 1992).

We found the key to accommodating the diverse learning style preferences as well as experience levels of the students to be providing a number of qualitatively different types of activities for them to engage in, as well as a number of different ways to excel. What binds the course together is its overall research flavor. The majority of the learning takes place in student-directed projects, in which the students have the opportunity to spend a large portion of their time pursuing in depth the aspects that most interest them. The students perform a large portion of their work in groups and have the responsibility of reporting their results as a group in the form of oral and written presentations to the class as a whole. The faculty and student staff in this course serve as consultants, guides, and cheerleaders to this process. We regard our primary role as instructors as one of helping students get to the stage of beginning to formulate questions of interest to them, as well as strategies for solving these questions. The principal challenge of the course is to find an

appropriate balance between enough freedom for students to blossom as independent agents and enough structure so that they feel secure.

While the ratio of structured activity to student-initiated projects is tailorable to an individual student's needs or interests, each of the students must engage in some exploratory activity for at least three of the modules. This activity may take the form of hands-on experimental work with engineering materials and departmental lab facilities, computational work, design projects, or library research. The results of all three activities must be presented to the rest of the class in some form, the emphasis being on creating a community of scholars. During the quarter each student will be involved in

(1) At least one contribution to the class, undertaken independently, concerning some aspect of the material covered in the course which the student has chosen to explore in more detail.
(2) Another contribution to the class, undertaken in a small group of 2–4 people.
(3) A large-team presentation of the results of the work undertaken in Module 9, "What's In It and Why?".

The curricular content of the course has also been significantly modified and reflects a major rethinking of what should be taught to the general engineering student in an introductory materials science subject. In fact, we believe that, in general, significant change in classroom practice will not be able to thrive without concomitant re-evaluation of curricular content. In our new course, we have recast the traditional content of a materials science course into a series of nine modules, which, though largely independent, share a number of powerful unifying conceptual themes, in particular the closely related ones of symmetry and thermodynamic driving forces. The modules are entitled "Symmetry," "Ferroelectricity," "Solidification," "Diffraction and the Determination of Structure," "Mechanical Properties of Materials," "Glass," "Biological Materials," "Semiconductivity and Superconductivity," and "What's In It and Why?". Each of our modules has a number of common components. They include an "idea sheet," which can act as a launching pad for students who have a hard time getting going on their projects, some textual material, outlining the fundamental concepts, a lab handout explaining the activities that will take place in the structured lab period, a reference sheet, and an optional problem set, for those who find that medium useful. For each module, the students are required to do the problem set or some independent work of their own choosing. In addition, a final exam is given, with the primary purpose of allowing those students who shine in that format to improve their grade in that manner, if they wish; the final exam is counted only if it improves the student's grade. This flexible structure enables those students who feel more comfortable with the traditional format of homework, quizzes, and exams to rely heavily on those activities, while those who prefer to explore their own ideas in depth can do so.

It should be noted that the modules were designed with a variety of objectives in mind. The majority of the activities in each module should be readily transportable to other engineering schools. In fact, they should be able to be used as supplements for a great variety of other courses in numerous non-materials-science departments. While some activities may call for sophisticated experimental equipment not available at each school, the modules are designed so that the major content is accessible to those lacking the equipment. Similarly, almost all of the modules are enriched by some computer-based activities, but none of the modules require computers. Portions of each module will certainly be appropriate for high school students as part of the ECSEL outreach program. The modules are designed to promote an interdisciplinary approach in their teaching and to encourage hands-on manipulative activity, as well as to involve students in the process of design. An important role of the structured experimental activity that is a portion of each module is to provide students with an appreciation of the

facilities that are available to them for subsequent use in their independent or group projects. These modules are the subject of ongoing development; our current goal is to have them ready for trial use at other ECSEL universities by the spring quarter of 1993 and for general dissemination by the fall of 1993.

The hours we spend together as a class are used for a variety of activities. We have two hours per week that are "lecturelike" in character, or approximately two hours per module. For each module, we also have one two-hour-long structured lab. In addition, for each module we have two more "free-form" class hours to play with. We use one in a rather novel small-group discussion process, wherein students brainstorm about ideas for projects, which are subsequently added to the idea sheet data bank. The other hour is used for more brainstorming about projects, and, as the quarter progresses, for student presentations. Outside of class, our department has dedicated one large lab to be the "ECSEL Playroom." This room contains some small-scale experimental equipment, computers, books, and tables. It is a place where students can do work, plan projects and presentations, consult staff, or simply spend time together, again, enhancing the sense of community.

The presence of such a constellation of activities has the real potential of promoting diversity. However, if our methods of evaluating and grading our students' work do not change in tandem, we are unlikely to have much of a profound effect. For our course, we hit upon a grading scheme called "journal-based assessment" which is well suited to its structure and which ends up having a number of complementary exciting benefits. For our class, the vast majority of a student's grade is based on his or her accumulated experience as recorded in a journal which consists of a daily log and a portfolio. The daily log is a rather free-form record of what the student is actually accomplishing on a day-to-day basis in this class. The daily logs serve as a record of conceptual difficulties and experimental observations, as well as comments and suggestions about the structure of the course. A vital function of the daily log is to encourage the student to begin to formulate the questions that he or she would solve if the resources were available. The daily-log observations are recorded in a bound notebook. We do not require that entries be made every day; on the other hand, we encourage students to make entries whenever they have done some work for the course, or whenever something comes to mind. These daily logs are to be graded strictly on a pass/fail basis. Because the daily logs serve as a powerful communications link between instructor and student, we recommend that the instructors keep logs as well, in which their reflections, however brief, on the progress of the class, new ideas for teaching, etc., are recorded. If these logs are periodically made available to the students, the reciprocity of this process can be greatly enhanced.

In the portfolio section of their journals, the students have the opportunity to take a body of work and continually refine it during the quarter. The portfolio is thus a concrete record of their accomplishment, in a form of which they can be proud. All of the work that forms the three presentations, as described above, is part of the portfolio. The portfolio also includes any other optional work undertaken as part of the nine modules. It is worth noting that the portfolio need not consist solely of written material. Numerous other formats have been very effective and fun, including video, computer projects, and concrete material objects. Again, the only limitation is the student's imagination.

Our journal-based assessment strategy is an essential aspect of the structure of our course, offering numerous benefits, including greater insight by professors into students' conceptual development, opportunities for students to reflect on their own learning styles, a mechanism for formative evaluation of students' work, increased communication level between staff and students, and greater involvement of students in the process of educational transformation. From the point of view of promoting diversity, journal-based assessment provides students with the opportunity to design personalized paths of

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intellectual development. Indeed, the first time we taught in this format, the top two students in the class were the student who had come into the class with the highest prior grade point average and the student who had come into the class with the lowest prior grade point average; the ways in which they excelled were indeed qualitatively quite distinct.

Some Symmetry Activities

It is probably useful to look at one set of activities in a bit more detail to get a clearer picture of how students with diverse needs and aspirations can be served in a class like ours. Note that, while these are mostly activities that we have created, our students are encouraged to dream up their own activities, as part of the projects they undertake in our course, many of which subsequently become part of future iterations. For this paper, we have chosen to address a set of activities associated with the first module in our course, that devoted to symmetry. Symmetry is a very powerful conceptual theme, which provides important simplifications in all branches of mathematics, the physical sciences, and engineering. Symmetry also clearly holds very valuable appeal to the human aesthetic. As such, symmetry is one of the unifying concepts of our new materials science course, and the activities described below are designed to shed light on that ubiquitous topic from a number of angles. Within our course, the students can undertake these activities individually or in small groups, subsequently sharing their insights and experiences with the larger group. We attempt to provide some unifying understanding through large group "lecturelike" sessions, as well as through readings. Portions of Activity 2, in which some of the nitty-gritty aspects of the most common crystal structures are elucidated, are engaged in by all students, because we subsequently lean on this knowledge so heavily. However, for the general use of this activity in promoting an understanding of symmetry as part of some other course or program, this activity could be of equal rank with the others. All of the activities are designed to exhibit exciting links with each other, so that the subsequent large-group discussions and projects that follow can have a rich basis for interaction. So what are the relative virtues of the diverse activities presented here and to what students might they be attractive? I provide a brief description of each of the activities below, together with an indication of how they hang together as a whole.

Activity 1. Origami Structures

Our first activity revolves around the construction of a number of origami cubes. While the basic external morphologies of the cubes are the same, their point symmetries are not. It is a useful exercise for students to work, either singly or in teams, to construct the various cubes, and to use them to enumerate the specific ways in which their symmetries differ. Ties can subsequently be made to specific crystalline systems exhibiting identical symmetries. What will quickly become apparent to the students is that the mechanical strengths of the cubes also differ greatly from cube to cube, as well as with different orientations of applied load for a single cube. Thus the activity can naturally lead to a discussion of the tensor properties of crystals, in general, and of their mechanical response, in particular. A subsequent origami design contest, in which students maximize the load carrying capacity per sheet of a structure of their own devising has been a highly enjoyable and informative off-shoot of this activity. Origami, in general, appeals to the artistic bent of our students, as well as giving them the opportunity to share and show off what they are doing in our class with their nontechnical friends, a nontrivial benefit. The activity lends itself well to team playing, as there are so many variations on cubes. Added challenges to students can be to come up with new cube-creating algorithms. In addition, other polygonal shapes, as well as connecting pieces, can be built, giving students the capability of creating a wide variety of "crystal" structures and of linking with the model

building in Activity 2. Additional advantages of this activity are that it costs next to nothing and that it can be done almost anywhere (almost as good as knitting in that respect!).

Activity 2. Building Models of Crystal Structures

This activity is the one most closely related to what would be considered a traditional materials science curriculum. Nevertheless, it could be valuable as a general purpose activity for elucidating the relations between underlying symmetries and external form, as well as the role symmetries play in constraining physical properties, in a more general physical science or engineering subject. We employ two techniques for creating the models: The first uses styrofoam balls and pipe cleaners. The second, itself a spin-off from a student project in our course, uses a more novel combination of sticks and medical sutures. The latter offers some important advantages by comparison with traditional ball-and-stick crystallographic models, in that it can tolerate an arbitrary coordination number at any atomic site as well as provide a degree of mechanical flexibility. We see some advantage in having groups of students work simultaneously using the two different media and then engaging in a large group discussion of the relative merits of the two techniques for elucidating the important physical features. After playing with some of the most common metallic structures, we typically move on to ionic crystals and to the structural distortions that accompany ferroelectric phase transitions. Through discussions of the point symmetries present at the various locations in the crystal structure, the students working on this activity can be in a position to advise the students in the origami group as to how to link polyhedra of varying symmetry to make larger-scale models of crystal structures. This activity appeals to folks who enjoy building concrete objects and who find the abstract discussions of symmetry rather hollow in their absence. It's also well suited for making connections to several concrete aspects of materials science, such as mechanical properties of materials and crystallographic forms appearing in nature.

Activity 3. Mathematical Representations of Symmetry Operations

An underlying mathematics particularly well suited for dealing with the symmetries with which we are working, and one which relies very little on previous experience, is the theory of groups. We try in our class to provide students with some exposure and experience in using very elementary group theory, casting everything in a straightforward geometric perspective, which also links very nicely with our hands-on model building. For some students this introduction will whet their appetite for a more thorough exploration, which will certainly stand them in good stead in future math, science, and engineering courses. As a beginning, we offer them a chance to explore matrix representations of the point symmetry operations present in crystals. Since they may have had little exposure to linear algebra at this stage, we start by having them figure out how the coordinate system transforms under various symmetry operations and construct the matrices from that understanding. They can then go on to look at the relations between various symmetries and the consequences of performing multiple operations in terms of matrix multiplication. With a little fooling around, the students can confirm that the various symmetries present in a physical object always satisfy the postulates of a group. Students can do this with pencil and paper, or with decent calculators, or with a symbolic math package, such as Theorist for the Macintosh. The latter has the advantage of enabling students to generate complex geometrics of their own choosing and to examine the consequences of operating on these structures with various crystallographic point symmetry operations. With any of these methodologies, however, connections can be made to the work of the physical model builders. The math group can share with them the systematic understanding that the group theory provides, while the modelers can provide

the math group with a concrete system to visualize group operations.

Activity 4. Building Symmetric Patterns with Computers

A wide variety of options exist for generating patterns exhibiting characteristic crystallographic symmetries using computers. One can choose among them based on availability of software, the time available for the process, and interest or experience in programming. The options include special purpose software, such as Crystal Paint for the Macintosh, which has a MacPaint-like interface, but enables the user to choose among either the two-dimensional periodic groups or a variety of point symmetries. Also in this category, in the public domain, is Crystal, from NorthStar Software, which allows the creation and manipulation of arbitrary crystal structures. Perhaps more beneficial in the long run is to give students access to general purpose software and let them figure out how to use it to generate patterns of their choosing. For two-dimensional periodic patterns, they can profitably play with ClaridCad, or similar software. Yet another option, which has the potential to give them a great deal of insight into the underlying symmetries while simultaneously providing some appreciation of programming to even the most inexperienced novice, is to work with them on Logo, which is very well suited to crystallography. In our course, because the time we have to devote is rather limited, only one of these activities is engaged in by all students, and that is the two-dimensional periodic pattern generation with Crystal Paint. That is because we subsequently employ their patterns in an optical diffraction activity. However, all of the other options have been taken on by numerous students, either as individual or small-group projects. Because they appeal so strongly to the artistic sense of our students, as well as provide another view on the meaning of the symmetry groups, these computer activities are quite popular. Again, students who master one or more methods for computer generation of symmetric patterns are in an excellent position to share their insight with groups that create physical models as well as with those who work on understanding the underlying mathematical structure of groups.

Summary

We created a dramatically new materials science course under the ECSEL program at the University of Washington, one which was explicitly designed with the goal of promoting diversity in the engineering endeavor. Because it embodies educational practices quite beyond the norm in engineering and because some of these practices are quite demanding of both human and material resources, it has been a very great challenge to move toward widespread acceptance of our course. Nevertheless, the current plan is that the ECSEL version will totally replace the traditional one by the fall of 1993, at which point it will serve as many as 800 students per year. One of the most gratifying aspects of the pilot versions of the course has been to see the ways in which students have indeed seized upon the opportunity to engage in diverse dimensions of our field. Students more wedded to traditional approaches can and do excel, but those who have often felt alienated or marginalized can also thrive. The set of symmetry exercises we described above is just one example of a set of disparate yet mutually reinforcing activities. While the framework in which these particular activities are housed is an introductory subject in materials science, they could be used in a great variety of contexts. On the other hand, we believe that materials science, as a field, should be one that more aspiring teachers should be encouraged to explore, though it is not now often on their agenda. It has a natural centrality to engineering and science endeavors that makes it particularly attractive for a person desiring a broad education at the undergraduate level. We also believe that our general strategy in this course, i.e., offering our students an array of qualitatively different yet mutually reinforcing options to excel, is a sound one for promoting respect for diversity. We hope

that this description of our course design may have some general utility for others engaged in their own curricular reform efforts.

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Various Teaching Strategies in Entry-Level Geology Courses: Opportunities for Students with Different Backgrounds and Learning Styles

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Introduction

Entry-level science courses play an important role in the education of both science and non-science-majors, in part because they offer an opportunity to create or foster a continuing interest in science whether a student becomes a scientist, a teacher, or a citizen able to make informed decisions on scientific and technological issues. The main teaching method in many entry-level courses, particularly those with large enrollments, is lecturing. One way to make such courses more appropriate for a diverse student population is to provide a variety of learning experiences. When students read journal articles, discuss topics with other students, write papers, give talks, and prepare group reports as well as listen to lectures, take notes, and read textbooks, opportunities for learning are expanded. Recognizing that students have different backgrounds, learning styles, and interests, teachers can design courses that better meet the needs of all students. Giving a variety of assignments in a diverse classroom will give individuals the opportunity to use their preferred learning style and will expose all students to different learning strategies (Anderson and Adams, 1992).

In this paper, I describe three teaching strategies used to supplement lectures: writing assignments, small-group activities, and volunteer extracurricular opportunities. These strategies not only recognize and build on student diversity, but also provide models for future teachers. My examples are drawn from Physical and Historical Geology courses with enrollments of ~100 and 50 students, respectively. Physical Geology is the first geology course that students take and includes both majors and nonmajors. A majority of the students are in the course to fulfill a general education requirement and more than a few admit they are scared of science. Historical Geology is one of the courses students can take after completing Physical Geology.

Writing Assignments

Writing assignments are a particularly appropriate teaching strategy in a science course taken by both science and non-science-majors. Many students who are not confident about their scientific abilities are more confident about their writing abilities. When asked to write a paper, even one on a geological topic, they believe that the assignment is building on one of their

strengths When students have some choice in a paper topic, they can select a topic of greater personal interest, which individualizes the assignment. Students learn more effectively when they are engaged in the subject matter, which is more likely when they choose or develop their own project.

The close relationship between writing and learning forms the basis of the writing-across--the-curriculum movement, in which writing assignments are given in courses in all disciplines to reinforce writing skills and to teach content. Thus, writing is viewed as both a product and a process. Descriptions of numerous writing assignments used in geology courses are given in the May 1991 issue of the *Journal of Geological Education*. Writing assignments used in entry-level geology courses include questions and answers, learning logs, in-class writing, journals, memos, reaction papers, summaries and abstracts of journal articles, laboratory reports, position papers, technical reports, and research papers (Cropp, 1980; Pinet, 1989; Clemons, 1991; and Macdonald, Conrad, and Kennedy, 1992). Assignments may be *informal*, those in which errors in the form of the writing are not counted against the student, or *formal*, those in which a final polished form is required. The assignments provide students with opportunities to write about geology and can increase communication between instructor and students.

I use both informal and formal writing assignments. Informal assignments include in-class writing and reaction papers and are generally short. Students may define a term in their own words, answer a question I have just posed, or write a question they have about the lecture material. Reaction papers are short papers in which students write their reactions to a lecture given by a visiting speaker and include one or more questions arising from the talk. Formal assignments include two or three short papers. The number of possible paper topics is unlimited and decisions on topics could be based on the interests of the students in the course. Students seem to be most interested in writing papers on topics that relate geology to some "real-life" experience or problem. Paper topics and formats include the following:

- Description and interpretation of a rock provided by the instructor or found by the student; one for a "geologically literate" audience, another for a general audience;
- Career profile of a geoscientist based on a personal interview;
- Short guide to the geology of an area (near a student's home or a place they plan to visit);
- Letter to an elected official about an environmental issue (solid waste, water supply);
- Summary of a journal article, perhaps one on a topic of debate in the geological, scientific, or global community (extinctions at the Cretaceous/Tertiary boundary, global warming, sea level changes);
- Position paper on a controversial environmental topic (Conrad and Macdonald, 1991);

Some of the paper topics listed above lend themselves to group discussions. For example, students could summarize an article of their choice on Cretaceous/Tertiary extinctions, then participate in a discussion in which students present the views of the author whose paper they have read. I did this the last time I taught Historical Geology, and it was the most successful discussion I have ever seen in an entry-level course. Every time one student finished talking, three or four others wanted to talk.

An integral part of the short paper assignment is a peer review process (Macdonald, 1991). Groups of three or four students review and critique papers written by others in the group using a critique sheet made by the instructor; the critique sheet includes questions on content as well as form and style. The peer reviewers are encouraged to make constructive comments. When students with different backgrounds and confidence levels are encouraged to read each others papers, they help each other on different aspects of the assignment and learn about both the content of the paper and effective communication. Peer review stimulates discussion among students and helps authors improve their papers.

Giving different types of writing assignments recognizes and builds on the background, preparation, and experience of the students in the course. Throughout the course, students become more confident of their ability to do and understand geology and their ability to communicate orally and in writing.

Small-Group Activities

Another teaching strategy that provides an opportunity for students to participate actively in learning and builds on student diversity is small-group work. Small-group activities are those in which students work together to complete an assignment. Within the groups, students might collect data, explain concepts to each other, discuss ideas and results, summarize information individual members have collected, and make interpretations. For some assignments, each group prepares and then gives an oral or written report to the entire class. Groups need to be small enough so that everyone can participate. Small-group learning experiences and associated benefits are discussed by Sharan and Sharan (1976); Johnson, Johnson, Holubec, and Roy (1984); and Slavin, Sharan, Kagan, Hertz-Lazarowitz, Webb, and Schmuck (1985). The effectiveness of learning in groups is related in part to the greater amount of discussion between students. Small-group settings are generally viewed as hospitable to all students, but particularly to women and minorities (Sigma Xi, 1990).

Small-group activities have been used in some geology classrooms (Romey, 1974; Macdonald, 1989; and others). They have ranged in frequency from one-time activities to weekly components of the class. Examples include discussions, games, and various types of projects. Small-group activities give students in entry-level geology courses an opportunity, not generally available, to work together on an assignment. Groups can be used to introduce new material, reinforce basic information, and review material covered in lectures. These activities actively involve students in learning, encourage interactions among students, develop collaborative and communication skills, and generate interest in geology.

I have used three types of small-group activities in Physical and Historical Geology (Macdonald, 1992). These types of activity are particularly beneficial for students in large entry-level courses because they stimulate discussion of geology by students. Peer-review groups, in which students read and critique papers written by other students, were described earlier.

A small-group activity used as an introduction to fossils takes place during a three-hour laboratory in Historical Geology. The 20 to 25 students arrange themselves into groups of 3 or 4. Each group of students selects a group (phylum, class, or order) of fossils from a list provided by the instructor. The group studies the characteristics of groups of fossils such as corals or trilobites. They have 60–90 minutes to learn about "their fossils" and to prepare a short oral report to teach the other students what they have learned. To ensure that all students participate, each student must give part of their group's oral report. I provide each group with a tray of specimens and a variety of handouts. Questions on a separate sheet guide their reading. Because no one can read all the material in the time available, each student must share what he or she has learned with others in the group. Thus, the contributions of all students are needed for a successful presentation. After students study the samples and read the handouts, they discuss the material. During the presentations, students draw sketches on the blackboard and use new terminology with ease. Students are confident about what they have learned and are ready to share it with the rest of the class. Other students listen carefully to the reports as study of the fossils continues the following week.

This activity provides an opportunity for students to work together to learn material new to them and to organize a summary and then give it orally to the entire class. The students learn "how to learn" about fossils by studying one group in detail. They learn from each other, both within their own group and from other

groups. Responsibility for successful completion of the assignment is shared by group members.

A third small-group activity is a review of material previously covered in lectures on geologic history (Macdonald, 1989). Students work in groups of three or four to plan a short oral presentation on the highlights of the biologic, sedimentary, and tectonic events of one interval of geologic time. Everyone must participate in the presentation, and any format is acceptable. In some groups, individuals work independently on different aspects of the geology interval. The presentations of such groups are usually a series of individual reports. The presentations of the other groups exhibit a wide range of forms and are obviously the result of students working together in all stages of preparation. These presentations have included skits, ballads, news programs, and game shows. Students are encouraged to be creative, and they take advantage of the opportunity. This is another way to provide for the diverse talents of the students.

Extracurricular Opportunities

A third way to expand the experiences of students in introductory geology courses is to invite them to participate in some extracurricular activity. One such activity is a program that establishes partnering experiences between college students and elementary school teachers and students. A team consists of a elementary school teacher, a geology major, and a student who is taking (or has taken) Physical Geology. The college students give two or three presentations during the year to one elementary school class. To prepare, students attend two workshops. In the first workshop, the college students and elementary school teachers study an outcrop and collect fossils. In the second workshop, each team plans one presentation about fossils, drawing on their individual strengths to design appropriate activities. Although the teams have similar ideas, the ways in which they plan to implement them are different, reflecting the different approaches of the team members. This program draws on the background and experience of all those involved, and gives the college students an opportunity to share their knowledge of geology with others and to learn about teaching in elementary school. This could be the first experience in what may be a continuing involvement in local schools, either as a teacher or as a scientist who will volunteer with the schools. The partnering program, which this year involves 12 undergraduates and 6 fifth-grade teachers, is supported in part by a minigrant from the Southeastern Section of the Geological Society of America.

Although the partnering program includes only a few students, it provides one way for entry-level students to get involved in geology beyond the classroom. Other extracurricular activities in which students could be invited to participate include lectures given by visiting speakers, departmental field trips, and slide shows where geology majors and faculty talk briefly about summer work. They could also work with geology majors and faculty on their research, doing field or laboratory work.

Conclusion

Writing assignments and small-group activities used to supplement lectures in large entry-level geology courses will benefit the mixed audience of geology majors and non-geology-majors, of students with different learning styles, and of those who have different confidence levels in their ability to do geology. The use of multiple teaching strategies will result in a variety of learning experiences, giving students the opportunity to learn in a way appropriate for them. Many of the small-group activities require students to work together. It is through this type of interaction, where each person contributes something to another's learning experience, that diversity is not only acknowledged, but also valued. By completing these assignments, students will do all sorts of things they would not do in a large class taught only by lectures. They will learn more about geology, in part because they will actually do some of what geologists do. They might carefully study a rock, read articles

from scientific literature, become informed about debates in the geological community, or write papers relating geology to some societal issue. Perhaps more significantly, they will talk to each other about geology. Use of these teaching strategies will also demonstrate to future teachers that teaching need not be limited to lecturing. The partnering program exposes college students to the possibility of teaching as a career. When future elementary teachers develop a lesson while taking a science course, it may start them thinking about how to transfer what they are learning in geology to what they can use later in an elementary school classroom. Students have responded very positively to these assignments over the years. Such activities may produce a classroom climate more hospitable than that in a course in which lectures dominate, perhaps making the study of geology seem more inviting to groups traditionally underrepresented in science.

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Classroom Activities Remembered by Physical Science Students

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The verification of Snell's law of refraction is a beautiful classroom experiment. It is also boring and typically forgotten by students. There are, however, many experiments which every year grab the attention of students and are remembered. Many of these activities border on being parlor tricks, but are, in fact, of serious intent, being aimed at introducing, elucidating, or applying scientific principles.

There are usually several influences that give rise to the remembrance of classroom activities by students. It seems possible to isolate a few of the central recurring sources that contribute to the appeal. Four such factors are enumerated in the following paragraphs

- Some demonstrations are startling, especially those that involve unexpected loud sounds, such as explosions. Strong effects of this nature inherently draw the student's attention, making him or her receptive to discussion.
- Some exercises involve what appear to be discordant events—e.g., things move that should not, or things that should move do not. The perplexing observations create receptivity for the discussion and explanation that follow.
- Some experiments utilize a toy. Students seem to have an affinity for learning from something which is so obviously intended for play. When they become aware that a relevant scientific principle is involved in the mechanism, they are eager to learn the detailed explanation.
- Some materials are homemade by the teacher, their origins obvious to the students, who regularly appreciate that the teacher has created a scientific gadget out of "junk." Because the teacher is perceived to have made an extra effort on behalf of the students, they, in turn, respond by being especially receptive to the device's action and the subsequent discussion.

The following demonstrations, each of which embodies at least one of the above themes, can be performed:

1. Energy conservation of an ice-cream cone
2. Pop time from two length measurements
3. Thermal energy of a rubber ball
4. Waves in a singing rod
5. Inertia of "massless" rod
6. Embroidery hoop period
7. Drinking bird engine
8. Nailing down the pirate's plank
9. Moving lumber at a distance
10. Internal combustion cannon
11. Torque-free yo-yo
12. Highs and lows of the Doppler effect.

If activities of the type discussed here are considered worthy of being included in the armamentarium of the teacher, then they and many similar ones must be introduced to teachers for selection and application. The installation of mechanisms for the passing of such skills to new teachers should be a major consideration in the development of innovative educational programs.

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Valuing Diversity in the Educational Process: Teaching Biology from a Feminist Perspective

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A number of years ago I helped develop and began to teach a course within the interdisciplinary program, Nexa, at San Francisco State University (SFSU), entitled "Biological Sex and Cultural Gender." It is an upper-division, general education course which has a diverse enrollment of about 60 students. A feature of all Nexa courses is team teaching by two teachers from different disciplines, and I am now teaching the course with anthropologist 'rofessor Mina Caulfield, from the Women Studies program.

Originally the course was intended to address issues such as androcentrism and sexism in the literature of both fields dealing with sex and gender and to illustrate how biological determinist explanations of gender are contradicted by evidence from anthropology. Over the years our focus has broadened, and we now include topics such as historical changes in power differences between the sexes within cultures, sexuality and its importance in gender development, and prospects for change in gender relations in our society.

The feminist perspective that we bring to the class sets the stage for a recognition of the presence and influence of political perspectives in the science that we examine throughout the course. We utilize a set of readings to present the issues on which we focus. Some of the articles specifically criticize the "bad science" which forms the evidentiary support for biological determinist theories of gender development, while others point out the influence of ideology in interpretations of the data of much of the research into sex differences. Students are free in the discussions that take place in the classroom and in the papers they write during the semester to express their own perspectives coming from their own experiences.

One of the results of this freedom of expression is the coming out into the open of feelings of sexist repression that many of the women students have experienced in their lives, including their experiences as students. Gender relations in the classroom are complex and will not be fully addressed by simply increasing women's opportunities to speak out in class and to participate fully in all the opportunities available in a university, necessary though these steps are. We need, in addition, to understand the devaluation of women by our society, its pervasive nature, its origins, and its silencing of women's voices. The devaluing of women is not just "out there" in social ideology and institutions, in the sexist practices of admissions and hiring committees, but it is also to some extent within each of us, a part of our self-concept, largely subconscious but capable of being reflected upon if we choose to do so. An understanding of gender identity development in individuals and of the interaction between individual beliefs and cultural norms in influencing human behavior can help

to free up choices that may have been foreclosed by earlier experiences.

As an example of the kind of material which is used to support a biological determinist view of gender identity development, that is, the idea that gender flows more or less directly from anatomical sex, we use the much cited studies of Money and Ehrhardt and Meyer–Bahlburg (1981). We contrast this approach with the view eloquently expressed by Geertz (1965), that to be human is to have and to create culture. To illustrate well-documented, widely accepted results in biology, we use the functioning of genes and hormones in the development of the anatomy and physiology of the two sexes in normal development (Wilson, George, and Griffin, 1981).

The work of Money and Ehrhardt and Meyer–Bahlburg (1981) is the most commonly cited support for a biological view of the formation of one part of gender identity. To make the case for hormones, they have, I think unjustifiably, separated gender identity into core gender identity and gender role behavior. These authors have studied individuals with a variety of syndromes caused by abnormal hormonal environments during gestation. The result of the hormone exposure is often an ambiguity of the genitalia of the affected infants such that they appear to be neither male nor female but "intersexed." Most of the data on which the biological determinist position is based come from studies of individuals with congenital adrenal hyperplasia (CAH), a genetic condition of the fetal adrenal which allows excess androgen to be produced which then partially masculinizes the external genitalia of chromosomally female (XX) infants, some of whom in earlier decades were assigned as males because of the extensive masculinization of their genitalia and uncertainty as to their "true" sex. Many of these children have been followed for years with respect to their gender development and behavior, and the researchers conclude that the psychological development of gender identity as masculine or feminine depends on the sex of assignment and rearing, as long as such rearing is itself unambiguous. They illustrate this point convincingly in their study of CAH individuals. For example, a CAH female infant with enlarged clitoris is assigned as a boy and raised unambiguously as a boy; he then undergoes a devastating feminizing puberty and is overjoyed to realize that with medical and surgical treatment he will not have to live with breasts the rest of his life. In contrast, CAH individuals reared in a social environment of uncertainty as to their sex, with inadequate medical treatment and consequent disparity between sex of assignment and pubertal development may decide on a sex reassignment at puberty, although this is, of course, rare.

In contrast to this clearly socially learned psychological component of the developing gendered self, Money and Ehrhardt and Meyer–Bahlburg (1981) postulate that gender role behavior, which they define as part of gender identity and as the behavior an individual expresses in order to present him/herself to the world as belonging to one or the other gender, is at least in part, influenced by the prenatal hormonal environment. They find that, when CAH girls reared unambiguously as girls are compared with normal girls, more of the CAH group prefer childhood play with boys in vigorous outdoor sports over playing with dolls in a more stereotypically feminine fashion. They also express a preference for a career over marriage and show less interest in infant care than do most of their peers. On the basis of analogy with various animal models in which mating behavior or juvenile play behavior seems to be altered by the action of perinatal hormone treatment on the brain, the researchers claim a causative role for hormones in the CAH children's behaviors.

In spite of widespread criticism of these studies on the basis of methodological inadequacies as well as the nonhomology of the CAH girls' behaviors with the animal behaviors studied and in spite of published accounts of CAH children who do not fit the pattern described by Money and Ehrhardt and Meyer–Bahlburg (1981), but instead demonstrate behavior which is similar to that of other children with serious childhood medical problems (Slijper, 1984), these

studies are claimed as the primary support for a role of hormones in gender identity development. And of course the finding of a hormonal role here is often used to bolster claims for a role of hormones in other aspects of our sex lives such as sexual orientation, as well as for alleged differences in cognitive abilities between the sexes.

Another striking and poignant example of an individual with abnormal prenatal hormonal environment, in which the consequences were tragic, is the story of Herculine Barbin, whose journal was discovered and published in 1980 by Michel Foucault. Herculine Barbin was born in rural France in the middle 1800's to a relatively impoverished family and raised unambiguously as a girl in a conventional feminine environment of convent schools. Nothing was noted regarding ambiguity of her genitalia on her birth certificate. She was successful in her schooling and happy to succeed in her normal school training and to receive a position in a private girl's school after her graduation at the top of her class. She was, however, disturbed as the years of adolescence passed at her failure to menstruate and to develop a feminine physique, including a failure of breast development.

Herculine fell in love with a young teacher, Sara, at the school where she taught and they carried on an affair for over a year during which she came to realize she was playing a more masculine than feminine role in her physical relations with Sara. The affair was ended after Herculine had to consult a physician, and eventually a priest, because of painful episodes associated with attempts by her undescended testes to descend into a nonexistent scrotum.

The discovery of Herculine's "true" sex necessitated her undergoing a sex reassignment, since the rule of law at that time in France was that gonads determined sex and gender. After years of attempting unsuccessfully to live as a man, Herculine, now known as Abel, killed himself. At autopsy he was found to have a partially erectile penis, ejaculatory ducts, and a small vagina. She/he was probably a case of 5-alpha reductase deficiency, another of the causes of ambiguous genitalia. In these cases the external genitalia fail to masculinize fully because of lack of conversion of testosterone to dihydrotestosterone at the appropriate time during gestation. The questions that can be asked about Herculine Barbin are fascinating, and she tells us much about our beliefs regarding both gender and sexuality. Students generally agree that her gender identity and gender role behavior were unambiguously feminine, concordant with her sex of rearing. Most of them also think her relationship with Sara was lesbian, which raises considerable discussion about the social construction of sexuality.

Telling though these case histories are, the data that we believe most convincing with respect to the social construction of gender and sexuality come from the study of other cultures in which cross-gender and third gender roles are well documented (Blackwood, 1984) and where gender roles may change throughout the life span of both men and women (Meigs, 1990).

The main point that I want to make with respect to the teaching of biology so that an understanding of diversity and the need for an egalitarian perspective can be appreciated, is that it is essential to show that biology has been, and is still used to support theories of male dominance in our society and that there is a great deal of material in the literature that can be used to broaden the perspectives of students with respect to gender, and to race and class as well (Kessler and McKenna, 1978; Dupre, 1990; Weeks, 1986). Opportunities to do this arise naturally in the teaching of the physiology of reproduction, of evolution, especially sociobiological views of human evolution (Longino and Doell, 1983; Dupre, 1990) and in genetics with its recent offspring—biotechnology. I think it is appropriate to seize these opportunities in all of the sciences to demonstrate the pervasiveness of gender issues in our lives, in and out of the classroom.

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A Holistic Understanding of Diversity in Teacher Education

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Framework

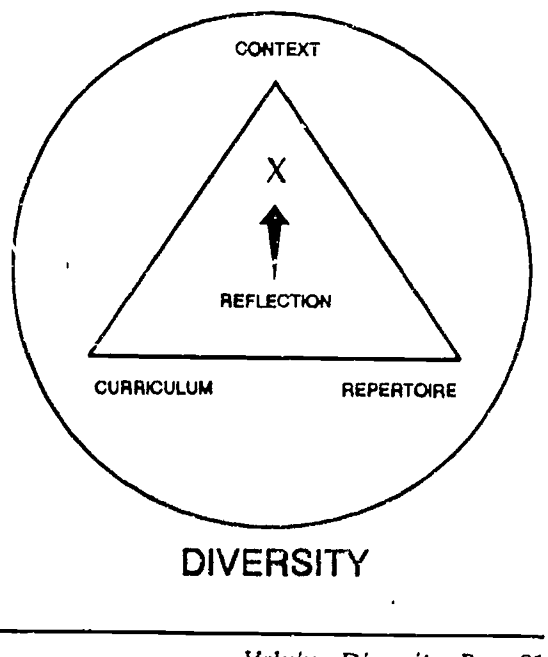
Valuing diversity in the educational process is more than finding an appropriate learning strategy or activity to meet the learning needs of particular individuals. Any one activity simply illustrates how to begin to think about addressing the diverse needs in a classroom. Attitudes toward diverse groups and systemic issues within educational programs must also be addressed. All students bring diverse interests to the mathematics and science classrooms, not just those who are often identified when talking about diversity: people of color and women. The way in which college professors think and act in relation to the issues of diversity will frequently be reflected in the kind of teachers of mathematics and science who come through their classrooms. College professors need to broaden their ways of communicating with their students. Teacher education candidates are influenced by all who come in contact with them.

The systemic issues in a teacher education model might be conceptualized in the following diagram. Diversity issues should permeate all aspects of the program. The X represents any specific learning strategy or activity. This learning activity is offered to teacher education candidates in asking them to reflect upon their individual needs. In fact, it is important to develop a repertoire of instructional strategies to meet different instructional goals as well as individual needs. In addition, all aspects of the curriculum should reflect the diversity of the society. Finally, the context of the educational setting needs to be considered from the perspective of the diversity issues.

An Example—CITE

An alternative program in teacher education has been initiated at the University of Maryland at College Park to address the issue of diversity from a holistic perspective. This program, Creative Initiatives in Teacher Education (CITE), is a collaborative program between the University of Maryland at College Park and the Montgomery County, Maryland, Public Schools. The program was originated with the goal of tapping

Teacher Education Model



DIVERSITY

nontraditional sources of minority teaching talent in order to increase the number of minorities teaching in the elementary schools of Montgomery County. The first cohort was admitted to the program in 1988.

Participants in the program are instructional assistants in the school district who have bachelor's degrees in different content areas. The program is a two-year program in which these instructional assistants become teacher interns involved in coursework and internships in addition to their usual responsibilities. The internships are one-third of their paid time. Graduates of the program at the end of two years receive a master's degree and elementary school certification. They have priority for teaching positions in the Montgomery County Public Schools.

The participants in the program represent Caucasian, African-American, Asian, and Hispanic populations, with 80% being people of color. During the planning for the program, there was considerable discussion around the issue of whether to devote the resources of the program solely to people of color. However, the decision was made to include white participants in the cohort in order to address directly the issues of diversity in the program. The interns are placed in schools where they work with diverse populations using curriculum and instructional strategies that emphasize success for all students. Success for all students becomes a pervasive expectation rather than merely a slogan.

The staff of the program also represent different racial backgrounds. They model working with the cohort in the way they expect the interns to work with their students in the classroom. This includes taking the mandate for success for all students in the CITE program seriously. There is an expectation of successful completion of the program by each individual participating at a high level of quality in all academic knowledge as well as in pedagogy. The program models at all levels appropriate ways of valuing diversity.

The CITE program is built around four themes:

- building a *REPERTOIRE* of instructional strategies for all participants,
- utilizing the *RESEARCH* in teaching and teacher education to ensure success for all and engaging in action research projects,
- engaging in a variety of modes of *REFLECTION* to ensure teachers who are truly reflective practitioners, and
- developing positive *RELATIONSHIPS* with students, parents, administrators, and colleagues.

Programs such as CITE, that approach the valuing of diversity at all levels, are necessary to bring about the kind of sustained focus on diversity required for the current educational challenges.

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[Bess Howard has contributed a student booklet and collaborated on a specific teacher training manual with student activities to encourage persistence in school. This is the kind of resource that will enable teachers to work effectively with students who are not successful in public schools because they have not learned to persist.]

Every Course Differently: Diversity and College Teaching An Outline

Craig E. Nelson, Indiana University at Bloomington

A Fundamental Point: I believe that bias has been (and is) so deep in our society that no one is free of sexism, racism, and classism. Further, our ability to recognize bias is deepening rapidly so that having our teaching up to last year's standards usually leaves a lot of room for improvement this year.

1. Can I Avoid Sexual Harassment and Stereotyping?

- In general, avoid saying or doing anything I would not say or do with/to both males and females and both students and colleagues.

2. Should I Use More Inclusive Language?

- Should I avoid male-dominated language constructions?
- Man, etc., versus plurals versus she, etc., in science to counteract stereotype? No choice is apolitical!
- Should I avoid spurious color-based idioms? Black and white, etc.

3. Should I Strive for More Neutral Classroom Behavior?

- Should I monitor my classroom interactions?
  - — Differences in frequency, level, and tone of responses and questions?
  - — Differences in eye contact and body language?
  - — Differences in form of address or number of names known?
  - — Differences in task assignment: deep end of Seine?
- Am I responsive to different modes of expression?
  - — Nondominant groups may be more tentative.
  - — Should I monitor student–student behavior?
  - — Patterns of interaction?
  - — Language?
  - — Old Boy behavior (arm punches, etc.)?

4. Should I Make the Content More Inclusive?

- Should I emphasize contributions by "others"?
  - — Seek out examples written by women, minorities, and from other cultures or subcultures?
  - — Specify first name to counter assumption that must be male?
  - — Specify coworkers and not just group directors? Women and minorities are much more frequent as coauthors, at least in science.
- Should I emphasize major results from non-patriarchal approaches? Do some differ qualitatively from contributions by rich white males?
  - — Evelyn Fox Keller on Barbara McClintock.
  - — Sarah Blafer Hrdy and Donna Haraway on primatology.
  - — Sue Rosser on women in science, general.

5. Which Among-Group Comparisons Are So Inherently Biased That I Should Teach Students To Distrust Them?

- Are we interested in differences among means or in overlaps among distributions? (Hare–Mustin and Marecek, 1990, 1988)

- Which pair-wise comparisons distort reality too much?
  - TIAA/CREF and sex-differential payouts (versus smoking).
  - "Black" and "white" reading achievement (versus class).
  - Simple-minded questions in a multifactor causal system can be so misleading that they should not be asked or taught!

6. Should I Emphasize Current and Recent Patterns of Discrimination in my Field and in its Applications?

- Where do different groups fall out of the pipeline to positions of major importance in my field?
  - In science, major exclusions in junior high, during college freshman year, entering graduate school, and entering post-doctorates and university jobs (NSF).
  - Differences between university and community college faculties.
  - Distribution of groups in research teams.
  - Distribution of groups within and among fields: math, physics, field-biology.
  - *Prima facie* evidence of discrimination?

7. Should I Make Deep Changes in Classroom Dynamics?
[See Especially Belenky et al. *(1986)]*

- Should I adopt a metaphor of teaching more in line with theories of learning as construction (versus copying): coach, midwife, experienced companion (versus "sage on the stage")?
- Should I be visible as a person with an explicit intellectual history, current intellectual commitments and doubts, and explicit value stances?
- Should I incorporate student experience and dialogue? e.g., student–student discussion (content and role structured but not certified).
- Should I foster less competition and more collaboration?
  - Do not grade on curve; revisable assignments.
  - Foster cooperative learning in class.
  - Foster out-of-class collaboration, explicit study questions, peer checking, etc.
- Have I noted Uri Treisman's work with calculus?
  - Teacher as responsible for social system. (Fullilove and Treisman, 1990)

8. Should I Make Fostering Intellectual and Ethical Development a Key Objective in my Courses?
[Perry (1970) and Belenky et al. *(1986)]*

- Prerequisite to the development of empathy and to appreciation of alternative perspectives and diversity.
- Prerequisite to understanding complex systems.
- Prerequisite to understanding limits of authority.
  - Sandra Harding (1986): "The first thing students need to know about science is the uncertainty inherent in its pronouncements."
  - Belenky *et al.* (1986): "...it is especially critical that teachers of science do all that they can to avoid the appearance of omniscience" [p. 216].
- There are three major teaching/learning tasks here.
  - Teach/see the sources of uncertainty in the discipline.
  - Teach/see how the discipline deals with this uncertainty and selects better theories/productions—i.e., the modes of argumentation and the criteria for choice (the ways of knowing).
  - Teach/see how the discipline embodies a particular value set and compare that value set with our own.

9. Should I Draw Out the Impacts of Social and Historical Contexts on my Discipline—Show How It Is Penetrated by Current Ideology?

- Word-choice: molecular "attacks" in chemistry (Beldecos *et al.*, 1988).
- Emancipated male birds (deprived of offspring care); indirect competition or indirect mutualism.
- Metaphors: development controlled by gravity or program (Gould, 1985).
  - Nucleus/cytoplasm & gender politics (Beldecos).
- Questions asked and not asked: polyandrous primate females (Sarah Blafer Hrdy).
- Focus on differences in means or on distributions (Hare–Mustin and Marecek, 1990, 1988).
- Questions funded and not funded (Harding, 1991, 1987, 1986):
  - Cancer and heart disease versus tropical diseases
  - Cure versus prevent cancer and ways to make a profit

10. To What Extent Does my Grading Scheme Act To Foster Mastery of my Field and to What Extent Does It Sort Students (Sometimes on Social-Class-Based Entry Characteristics)?

- Much college grading assumes the students can judge what to study, know how to write papers, have good time-management skills, etc.
- But there are class-based differences in the extent to which students have been pretrained in the conventions of our disciplines.
- There are also substantial differences in their preparation for long-term time-management tasks and in the extent to which their lives are likely to be inflexible (as from the demands of extensive employment) and seriously interrupted (as from family problems). Fixed deadline grading tends to exacerbate the impact of these differences. (Bowles and Gintis, 1973).
- Should I train students to take exams and write papers in the style of my discipline?
- Should I use an evaluation system that encourages mastery of the discipline?
  - More explicit designation of the learning tasks
  - Study questions (echo or use on exams)
  - Revisable papers; repeatable exams (new questions)
  - Cooperative assignments
  - Structured student–student discussion

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Research on Learning and Teaching Science and Mathematics

Joan Ferrini-Mundy, University of New Hampshire, Chair

Panel Members: Kathleen M. Fisher (San Diego State University), Jerry Guyden (The City College of New York), Thomas Henderson (Southern University), Harry P. Hopkins (Georgia State University), George R. Jiracek (San Diego State University), Priscilla Laws (Dickinson College), Suzanne M. Lea (University of North Carolina at Greensboro), Richard L. Magin (University of Illinois), David Peak (Union College, Schenectady, New York), Marcia Sward (Mathematical Association of America), Sigrid Wagner (Ohio State University), John Werth (The University of Texas at Austin)

Introduction

In planning our workshop, we focused on the role of research in mathematics and science education, concerning teaching and learning, in the process of preparing teachers. Our participants brought with them a range of experiences, viewpoints, and understanding of the research enterprise in teaching and learning. We began with a brief discussion of the nature of research in mathematics and science education, in particular the fact that it is moving from the early "agrarian" model of controlled experimentation toward more naturalistic and descriptive methodologies. We discussed Silver's notion (1990) that, not only the findings of educational research, but also the perspectives and the methodologies of educational research can have important implications for practice.

Early in the workshop we divided participants into small groups and asked them to consider their images of educational research and to discuss what questions research should answer. In true constructivist fashion, we believed it best to begin from gaining an understanding of the group's viewpoints, as opposed to imposing our own knowledge and understanding on them. The participants divided into two groups.

Images of Research

Summary of Group 1 Discussion
Suzanne M. Lea, Reporter

Participants primarily from content disciplines had some reservations about educational research. They described it as inconclusive and unclear in methodology. They commented that it used too much jargon. They described it as essential for elementary education but controversial when applied to secondary or undergraduate

education. Many believe that both faculty in content disciplines and teachers perceive educational research as irrelevant. One participant commented that his discipline was willing to talk to the school of education, but faculty there were not willing to talk to members of his department.

Participants from educational research defined educational research as a search for interventions affecting learning and for information about how students think. They described it as rich and vast, as not widely known nor valued by traditional scientists, mathematicians, and engineers, and as difficult to do well.

Both types of participants listed issues: educational research concerns itself with teaching methods, teaching effectiveness, equity, misconceptions, problem solving, listening to students think, and curriculum development. It uses both quantitative (statistical) and qualitative (descriptive) studies.

Discussion revealed that participants viewed individual results of educational research as fascinating but felt unsure of how to apply them to practice. One participant suggested including a speculative section in papers identifying student conceptual problems: the section would list possible untested intervention techniques to assist students with overcoming the problems. It was agreed unanimously that educational researchers should attempt to relate their work to practice and write summary articles free of educational jargon and that content specialists should strive to become familiar with the variety and extent of relevant educational research.

Summary of Group 2 Discussion
David Peak, Reporter

Impressions recorded by this subgroup of the participants spanned the full gamut of opinion: dry, not interesting; jargon-intensive; a fringe activity; too scholarly; arcane, irrelevant, unused; narrowly focused on how individuals master concepts—negligible impact in the classroom; a social science dealing with large numbers of ill-controlled and ill-defined variables; highly statistical—like much of social science, fashionably quantitative; difficult, a hard problem; exploratory; linked to cognitive science; evolving—very much a profession redefining itself; a challenge—an area of great excitement; radically new methods; exciting, stunning, and practical!

What Questions Should Research Answer?

Summary of Group 1 Discussion
Suzanne M. Lea, Reporter

Participants also were asked to address the topic of what questions they thought educational research should investigate, in the context of the undergraduate education of future teachers. One specific topic and two general questions were suggested, in addition to concerns about communicating useful results to traditional scientists, mathematicians, and engineers.

The general topics suggested were "How do we change teachers' ways of teaching?" and "How does the learning of process interact with the learning of content: Are they necessarily adversarial, or can they be synergistic?" Participants discussing the first question noted that teachers teach as they have been taught, and consequently new teaching methods must be modeled for teachers. They also noted that ongoing support from university faculty, school administrators, and the community are required to assist teachers who wish to change their ways of teaching.

The discussion of the second question was brief because of lack of time. It was noted that learning process along with content necessarily requires some reduction of content. The amount of reduction depends on what level of learning is desired, in the sense that, if one wishes to reach every student, the content must decrease by a larger amount than if one is satisfied to reach 75% of the students. Nevertheless, learning process and content together enables the teacher to reach more students (in the sense of improved attitudes and critical thinking skills) than using rote memory content learning alone. The similarity of inquiry methods used to teach content to research methods in the sciences was pointed

out: Undergraduates engaged in inquiry-based courses are actually performing research.

The specific question contributed was how, in computer science, to get a student to work at several levels of detail in a model and to change easily among the levels. Group members rephrased this question as how to find students who are able to perform this task and what can be done to help students who have difficulties. It was suggested that the participant asking this question should co-opt an educational researcher, working with this person to define the question further, and conduct with this person a study of the ways currently used to teach students to perform this task.

Participants suggested that more research is needed on the role of technology and its appropriate uses and impact. Participants reiterated a concern that educational researchers consider the problems of practice (curriculum and teaching methods) in their work. How principles can be communicated to practitioners and how the practitioner can assess results of educational research and evaluate controversies over appropriate teaching methods was of interest. Participants indicated interest in what they had heard about mathematics and physics education research and a desire to know more about results in the fields of computer science, chemistry, and biology. Educational researchers pointed out that useful research involves experiment as well as theory; the experiments should be conducted in real schools and universities in real settings. Funds and technological advances would increase the ease and efficiency with which data can be gathered, in order to decrease the time lag between gathering data and reporting results.

Summary of Group 2 Discussion
David Peak, Reporter

- What are alternative, cost-effective strategies for reaching large numbers of students (besides mass lectures)?
- How can educational research break away from "atomistic studies" and concentrate more on classroom- or instruction-based research?
- How do you know when something "works?" What does "works" mean? What, specifically, is it that "works?"
- Can appropriate assessment tools be developed to aid in achieving educational goals?
- What are relevant curricula and methodologies for diverse populations of students?
- Is remediation hopeless in science education?
- How can educators be educated? Why are academic scientists reluctant to take a scientific approach to questions of education?
- What is effective in changing people's beliefs? What is the effect of social conditioning on education? What role does evidence play?
- How do the (perceived) expectations of graduate schools color the way science education is practiced on all levels?

Sampler of Annotated Work

In an effort to provide participants with a sense of the range of research activity underway in mathematics and science, a number of individuals presented samples of recent work in the field. More detailed summaries and explanations, for all but the final sample, follow later in this chapter.

Sigrid Wagner presented an activity designed to help acquaint participants with research on student learning in the area of algebra and functions. Participants worked in pairs on a series of tasks typically used in research in this area, attempting to predict the solutions that precollege students might construct to the algebra problems. We then discussed as a group the sorts of findings that this extensive body of mathematics education research has revealed.

David Peak described a course he has developed for non-science-majors entitled "Order and Chaos: Art and Magic." Although Peak is the first to admit that the course is not consciously based on research, it takes seriously the view that students need to be actively engaged in their own learning; discovery is an important element.

We watched a videotape involving iterated function systems using video equipment, which is the basis for one of the laboratories in the course. Such ventures into curricular and pedagogical innovation at the undergraduate level can lead naturally to research questions about teaching and learning.

Kathleen Fisher demonstrated SemNet, a methodological tool that allows an individual to construct a network or web of concepts interlinked with named relations to describe a topic or domain of knowledge. This is a research tool used to elicit student knowledge.

Priscilla Laws introduced us to the notion of research-based curriculum. In particular she summarized some of the learning gains achieved from the Workshop Physics and Tools for Scientific Thinking programs and demonstrated the use of a motion detector to collect data in real time. The most recent summary of key research finding is contained in an article, "Why Don't Physics Students Understand Physics," (*Physics News*, 1992) written by her collaborator, Ronald Thornton.

Suzanne Lea discussed student understanding of certain fundamental physics concepts and introduced us to the research methodology of interviewing as a means of learning about students' misconceptions. In addition, he explored issues in computerized tests of student conceptual understanding.

Ray Hannapel, Program Office for the National Science Foundation's Research in Teaching and Learning Program, provided a videotape for the group to observe and discuss. "Group of Four" is a of tape of young students collaborating to solve the following counting problem: If you have Unifix cubes in two colors, how many different towers of height three can you build? The tape was made as part of a research program on children's learning in constructivist classrooms, directed by Carolyn Maher and Bob Davis at Rutgers University. The group was struck by the level of mathematical thinking and communication possible with young children. for additional reading in this area, see Davis, Maher, and Noddings (1990) and Martino and Maher (1991).

Discussion

As a means of arriving at conclusions for our group, we had a group discussion on the topic "What can be done by the various communities to enable research to influence practice in undergraduate science and mathematics teaching and in teacher preparation: educational researchers and disciplinary faculty, NSF, and professional organizations?" The following summary reflects the brainstorming character of the discussion, and the thoughts included below are not necessary indicative of strong consensus among the entire group.

General responses included the need for stronger communication and collaboration; the need for more research to help us understand the role of technology and computers in learning; the need for a clearinghouse or electronic database to help practitioners gain access to research; and the need for agenda-setting activities for research on teaching and learning at the undergraduate level.

Our group believed that educational researchers needed to conduct applied research, in classrooms, as a means of building credibility and utility for their work. Some believed that collaborations between educational researchers and disciplinary faculty should be stronger. There were suggestions that the educational research community members needed to be more "evangelistic" in their attempts to communicate with the disciplinary faculty, in particular by infiltrating existing journals read by mathematicians and scientists. At the same time, we believed that the disciplinary faculty might find ways to enlist prominent members of their community to collaborate in and write about educational research.

We brainstormed a number of activities for the National Science Foundation to consider workshops to convince prominent disciplinary faculty about the existence and usefulness of

educational research; summer workshops for faculty interested in learning to conduct educational research; better communication, using technological means; grants designed to encourage the participation of disciplinary faculty in ecucational research; the reward system which may fail to recognize the value of educational activity; public relations and the image of educational research; and the view that curricula are evolutionary and, as we learn more about how students learn, will continue to evolve. In this spirit, we discussed the need to build adaptable curricula and to encourage experimentation with curricula.

A number of suggestions were offered for professional organizations. These included the need for publication outlets for educational research; a focus on reaching senior leaders within the profession as part of the effort to promote the status of research; bulletin boards and special interest groups; lecture series, workshops, and speakers; and incorporation of research into the regular meeting structure.

Conclusions

We came to consensus on the following points:

- Attend to educational research findings; they are rich, substantive, and offer lots of directions for change
  - The need for change is well established
  - There is much to be done in teaching and in research
- Develop collaborations between educational research communities and practicing university science and mathematics faculty
  - Action research (engaging teachers in classroom research)
  - Curriculum development informed by research
  - Text writing informed by research
  - Result of collaboration: better practice, better research, more research
- Improve communication among educational researchers, scientists, mathematicians, teachers, curriculum developers
  - Educational research publications in discipline-oriented journals
  - National and local workshops
- Make research responsive to pressing questions in practice
  - For example, classroom-based research connects learning practices with outcomes
- Work toward change in reward systems (universities, schools, professional organizations)
  - Promotion of research and scholarship in learning/teaching

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Sample Tasks from Research on the Learning of Algebra

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With some notable exceptions, most of the research on the learning of algebra has been conducted with precollege students, yet the findings provide considerable insight into difficulties college students have in formulating equations, composing functions, interpreting graphs, or solving word problems. Recent overviews of research on algebra (Kieran, 1992; Wagner and Parker, 1993) show the variety of conceptual and procedural understandings probed in the area of algebra, particularly over the past 20–25 years.

In this paper, we will look at seven tasks reported or suggested in studies of algebra learning. Though these seven tasks are drawn from a variety of studies—some large-scale, some small-scale, some from the United States, and some from abroad—such a small number of tasks cannot begin to reflect the wealth of ideas embodied in the research literature. Nonetheless, they should convey the flavor of current efforts in mathematics education research and perhaps whet the reader's appetite for ideas that could enrich our teaching of undergraduate mathematics.

The mathematics education research community is international, both in perspective and in participation. Indeed, the modern era in research has roots in work begun in the Soviet Union and western Europe in the first half of this century. The theories of Vygotsky (Soviet Union), Piaget (Geneva), the van Hieles (Netherlands), Perry and Dienes (Great Britain), and Thorndike, Dewey, Brownwell, and Bruner (United States), along with many others, to this day provide the theoretical foundation for much of the research in mathematics education in this country and elsewhere.

For example, the huge Concepts in Secondary Mathematics and Science (CSMS) project conducted at Chelsea College, University of London, 1974–1979, used a Piagetian perspective to identify levels of understanding of a wide range of mathematical topics among 10,000 adolescents aged 11–16. The report on algebra (Kuchemann, 1981) includes a taxonomy of the ways students operate with variable. A simple task to illustrate the difficulty students have in grasping the basic notion of a variable is the following:

1. *What is the perimeter*
   of a regular pentagon of side 2 units?
   of a regular 20-sided figure of side 2 units?
   of a regular n*-sided figure of side 2 units?*

Most middle grades and high school students can find the first perimeter, and they can generalize their method to any specified number of sides. However, only 38% of the 14-year-olds in the CSMS project were able to wite an expression for the perimeter of a regular n-sided figure, each of whose sides has length 2. Results such as these are especially noteworthy when we realize that many 14-year-olds have already studied some algebra or prealgebra and most have seen variable used in a variety of contexts. A major contribution of research of this type is to show that students who perform satisfactorily in a limited number of predictable contexts (primarily on textbook exercises) may not have the depth of understanding we might assume.

One of the first things students learn about variables is that the choice of symbol is arbitrary, yet many of them fail to grasp the implications of the freedom of choice (Wagner, 983). Consider this task:

2. *Suppose you know that the solution of the equation* $3x - 5 = 2x + 10$ *is* $x = 15$*. What is the solution of the equation* $3y - 5 = 2y + 10$*? How can you tell?*

This task was inspired by conservation-of-equation tasks (Wagner, 1981) in which the letter

representing the unknown in an equation is changed and students are asked how the solution to the equation is affected. Unlike many younger students, college students conserve equation—that is, they recognize that changing the letter does not affect the structure of the equation, hence does not change the solution. Yet, when operating in contexts that are not so familiar as simple equations, even college students may betray their misconception that different letters must have different values.

The familiar juxtaposition, or concatenation, convention in algebra (3*a* means 3 times *a*) derives from two important consequences of using letters to represent numbers: First, letters can represent multidigit numbers, so the preoccupation with place value that suffuses the study of arithmetic is not a concern in algebra; second, using letters of the alphabet provides a symbol system that contrasts with Arabic numerals, thereby allowing us to interpret 3*a* as something other than a two-digit numeral. However, this wonderfully powerful notational convenience constitutes a "double whammy" for students learning algebra—not only do they have to learn a whole new symbol system in which concatenation is multiplicative, and not additive, as it is in arithmetic, but they also have to operate with both systems at the same time. As often as we appeal to students' knowledge of arithmetic to help them understand algebra, here is a case in which knowledge of arithmetic not only interferes with learning algebra but even causes continuing cognitive conflict. Our best hope is that all students become as consciously aware of the conflict as one student who asked:

3. *What is* 3a *when* a = *4?*

This student answered with a question of her own: do you want me to answer in arithmetic or "in algebra"? (Chalouh and Herscovics, 1988, p.41).

One task in which the parallel between algebra and arithmetic is valid and presumably obvious is the following:

4. *Multiply:* $(3x - 2)(2x + 5) =$ ________ .
Now factor this polynomial [interviewer points to the product the student has just written].

Even though students are drilled on inverse operations throughout elementary school, a significant number of college students fail to recognize immediately the inverse relation between multiplication and factoring in the context of college algebra (Rachlin, 1981). The complexity and time-consuming nature of algebraic manipulations apparently obscure the structural properties. As calculator-computers eliminate the need for tedious symbol manipulation, students may more easily apprehend the important relations that constitute, after all is said and done, the very essence of algebraic structure.

Another problem that was originally investigated with college students is possibly the single most researched task in algebra—the famous students-and-professors problem:

5. *There are 6 times as many students as professors in our university. Using* S *to represent the number of students and* P *to represent the number of professors, write an equation that describes this relationship.*

In one of the first studies of this and similar problems, an astonishingly high percentage of college students (37% of freshmen engineering majors and 57% of non-science-majors) committed the reversal error of writing $6S = P$ (Clement, Lochhead, and Monk, 1981). Subsequent studies have shown that this error is highly resistant to remediation. The fact that students can demonstrate clear understanding of the problem by drawing appropriate diagrams and providing plausible numerical instances, but still write the equation reversed, suggests that here is a case where language interferes with algebra. That is, "6 times as many students as professors' gets translated as $6S = p$. We may need to rethink the advice so often given students struggling with word problems—to translate the English sentenc-

es directly into algebraic equations. As often as that advice may be helpful, it may also encourage an overly simplistic approach to problem representation.

One of the mental facilities that is essential in higher mathematics and which we hope to develop in all students is the ability to unitize polynomial expressions as variables, that is, to regard a binomial such as $2z + 1$ as a variable unit. Parentheses often help students unitize (e.g., in factoring by grouping) by providing a visual unifier that helps overcome the separation induced by addition/subtraction operation signs. Ironically, in a problem such as the following (Wagner, Rachlin, and Jensen, 1984):

6. *Suppose* $5(2z + 1) = 10$
   Then $\frac{2z + 1}{2} = ?$

The usual admonition to "clear the equation of parentheses" subverts, for many students, any visual links between the first and second lines that might help them unitize the quantity $2z + 1$ and thus jump to the shortcut solution. Unitizing has been investigated extensively in connection with place value in the early grades and, to a lesser extent, in connection with fractions in the middle grades but has scarcely been more than identified at the level of algebra. At this point, we have yet to understand how this ability develops or how it can be fostered.

Function notation is notoriously difficult for algebra students. Just how difficult is illustrated by resultsfrom the Fourth Mathematics Assessment of the National Assessment of Educational Progress. Students were asked to find the value of a simple linear function in one of two formats:

7A. *What is the value of* $a + 7$ *when* $a = 5$?
7B. *If* $f(a) = a + 7$, *what is the value of* $f(5)$?

The results shown in Table 1 indicate that function notation alone causes a dramatic drop in performance even on this most straightforward kind of function task. The interested reader is referred to Ferrini-Mundy and Lauten (1993) and Leinhardt, Zaslvsky, and Stein (1990) for reviews of the extensive literature on function research.

The tasks described above are but a very small sample of the kinds of tasks that researchers have devised to gain a deeper understanding of how students construct concepts related to algebra. These tasks can alert us to conceptual irregularity often masked by procedural facility. More to the point, these tasks may suggest ways of promoting deeper understanding on the part of out students at all levels.

Table 1. Evaluating Functions

Item	Percent Correct [Response Rate] Grade 7	Grade 11 No Algebra	Grade 11 Algebra I	Grade 11 Algebra II
A. What is the value of $a + 7$ when $a = 5$?	77[0.90]	72[0.89]	94[0.94]	96[0.98]
B. If $f(a) = a + 7$, what is the value of $f(5)$?	*	31[0.52]	65[0.77]	79[0.84]

* Not administered at grade 7 (Lindquist, 1989, p. 62)

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Order and Chaos: Art and Magic

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This is a first course in quantitative thinking for college students with no special prior training beyond high school algebra and trigonometry. The course was specifically designed to incorporate some of the more important recent educational research findings: (a) people learn best by doing; (b) people learn best when what they are learning is relevant to their lives; and (c) beginning students often are profoundly handicapped in learning about the physical world because Newtonian concepts are alien to their everyday experiences and because their mechanical analytic skills are inadequate. Instead of the standard reductionist approach to understanding Nature, *Physics 40* meets complexity head on: Its subjects are the fractured forms and the fractured events of the real world. Since the natural and social sciences and the arts all grapple with complexity, albeit in idiosyncratic disciplinary ways, we are able to explore connections between these seemingly disparate enterprises.

We emphasize the power of mathematical modeling in comprehending our surroundings. But, we deemphasize classical analysis and focus, instead, on thinking in pictures—using the computer as essential to that task. We exploit the visual appeal of fractal geometry (and its close kin, chaotic dynamics) in this regard. Topics covered include image processing (using fractal algorithms), operational measurement of properties of natural fractals, noisy time series, the connection of noise to music and to the visual arts, the deterministic origins of (at least some) noise, detecting and controlling chaos, fractal basin boundaries and the fragility of order in the nonlinear universe, and the self-organizing character and emergent properties of cellular automata. The central theme throughout these discussions is that complexity can evolve from iterative (often relatively simple) nonlinear processing.

As much as possible we encourage discovery. The course has a laboratory in which students learn about such things as iterated function systems (fractal image processing), measuring fractal dimensions (paper wads make a nice example), periodic and aperiodic behavior in electronic circuits, pendula, and fluid systems. They are guided to ask "what if?" questions. Because much of what we discuss is so new, there are many opportunities for students to do original work: an essential part of the course experience is a term project. Examples of successful past projects are composing music based on fractal principles; relating the fractal dimensions of river networks to their ages; and probing weather, economic, and physiological time series for deterministic causes. At its best, the term project lends further support to the notion that research can be teaching of a very special and effective form.

[Excerpt from Chapter One of
Order and Chaos: Art and Magic
by David Peak and Michael Frame
(W.H. Freeman, 1993)]

Toward a Science of Complexity

Do the following statements sound familiar?

- "Well! Look who got up on the wrong side of the bed this morning"—a mother to her moody teenage son.
- "Right now, it looks like the weekend is going to be dry and pleasant, great for picnics and going to the beach. Of course, I don't really have that much confidence in forecasts so far down the line—a local TV meteorologist on the Monday six o'clock news.
- "Most of the blue chip stocks closed substantially lower today. It took me a bit by surprise, but, in retrospect, I think it was probably just a technical correction"—a stock broker speaking to her slightly bemused client.

Life is often complicated—sometimes exceedingly so. Much of our everyday experience is unexpected, apparently whimsical, seemingly beyond our control. On the other hand, we also commonly take for granted the long-term, reliable functioning of refrigerators and computers and communication satellites. How is it that some aspects of our experience are regular, predictable, tamable, while others appear to be the outcome of some cosmic game of chance? Is the universe a crazy patchwork of phenomena, some understandable, some beyond explanation?

Those aspects of our experience which we feel are most "under control" are typically linked to the ideas of science and the products of technology. You know, of course, that scientific writing often contains lots of mathematics. Despite suspicions to the contrary, the use of mathematics in science text is not meant to prevent the innocent reader from discovering profound, though perhaps dangerous, truths. Rather, it is meant to convey precision and promote clarity. It is a remarkable and mysterious fact that at least some pieces of the universe (the explainable ones) are best described in the language of mathematics.

Until very recently, scientists have been accustomed to describing the world in terms of what can be called "smooth" mathematics. Smooth mathematics is the mathematics of continuous and unjagged structures—unbroken lines, curves, surfaces, volumes. It includes major portions of arithmetic, algebra, geometry, and calculus. Its roots are as ancient as human history. Galileo, the first more-or-less modern scientist, expressed a deep belief that the geometry of Euclid is the language in which the secrets of the cosmos are written. Newton invented calculus, in part, to formally relate Euclidean geometry to the description of continuously evolving processes. The Euclidean–Galilean–Newtonian vision of the structure and dynamics of the universe has often proven to be extraordinarily useful. In large, it has propelled the machinery of technology; not coincidentally, this vision pervades much of contemporary Western thought.

So, then, is the universe partly Newtonian—smoothly continuous, a predictable clockwork mechanism—and partly messy stuff: social and psychological behaviors, aesthetics, emotions, spirituality, free will, random happenstance, and all that. No, such a dichotomy is too clean. Physical things that we feel should be intrinsically Newtonian are often quite unruly. Storms and earthquakes and tidal waves and all kinds of accidents elude prediction. And the shapes of a Nature aren't exactly smooth, either. Cezanne, in instructing his students to "treat nature in terms of the cylinder, the sphere, and the cone" (Gardner), preached pure Euclidean–Galilean–Newtonian dogma. While cylinders, spheres, and cones provide a kind of first-order approximation to reality, they also miss the essence of the natural. As the contemporary mathematician Benoit Mandelbrot has put it:

> "Many important spatial patterns of Nature are either irregular or fragmented to

such an extreme degree that Euclid—classical geometry—is hardly of any help in describing their form. The coastline of a typical oceanic island . . . is neither straight, nor circular, nor elliptic . . . . Similarly, no surface in Euclid represents adequately the boundaries of clouds or of rough turbulent wakes . . . many patterns of Nature . . . involve, in comparison to Euclid, not only a higher degree but an altogether different level of complexity." (Mandelbrot, 1977)

The wide availability in the last quarter of this century of high-speed computers with vast reserves of memory is rapidly transforming how we understand our surroundings. New notions and techniques are beginning to supplant some of the most venerated ideas of science and applied mathematics. Instead of approximating the inherently fractured character of Nature with smooth forms, these new methods grapple with fracture head on. Still very much an infant, this new science of complexity promises to describe the universe in much more accurate and appropriate terms, yielding, in consequence, deeper understanding and more reliable prediction. It also promises to much more closely ally the physical world with that of the mind, unifying what was previously dichotomous.

Using SemNet® as a Learning Tool in an Inquiry-Based Biology Class for Prospective Elementary School Teachers

Kathleen M. Fisher, San Diego State University

SemNet allows an individual to construct a network or web of concepts interlinked with named relations to describe a topic or domain of knowledge. The software supports construction of large multidimensional "concept maps." My students use this software to organize their knowledge about biology.

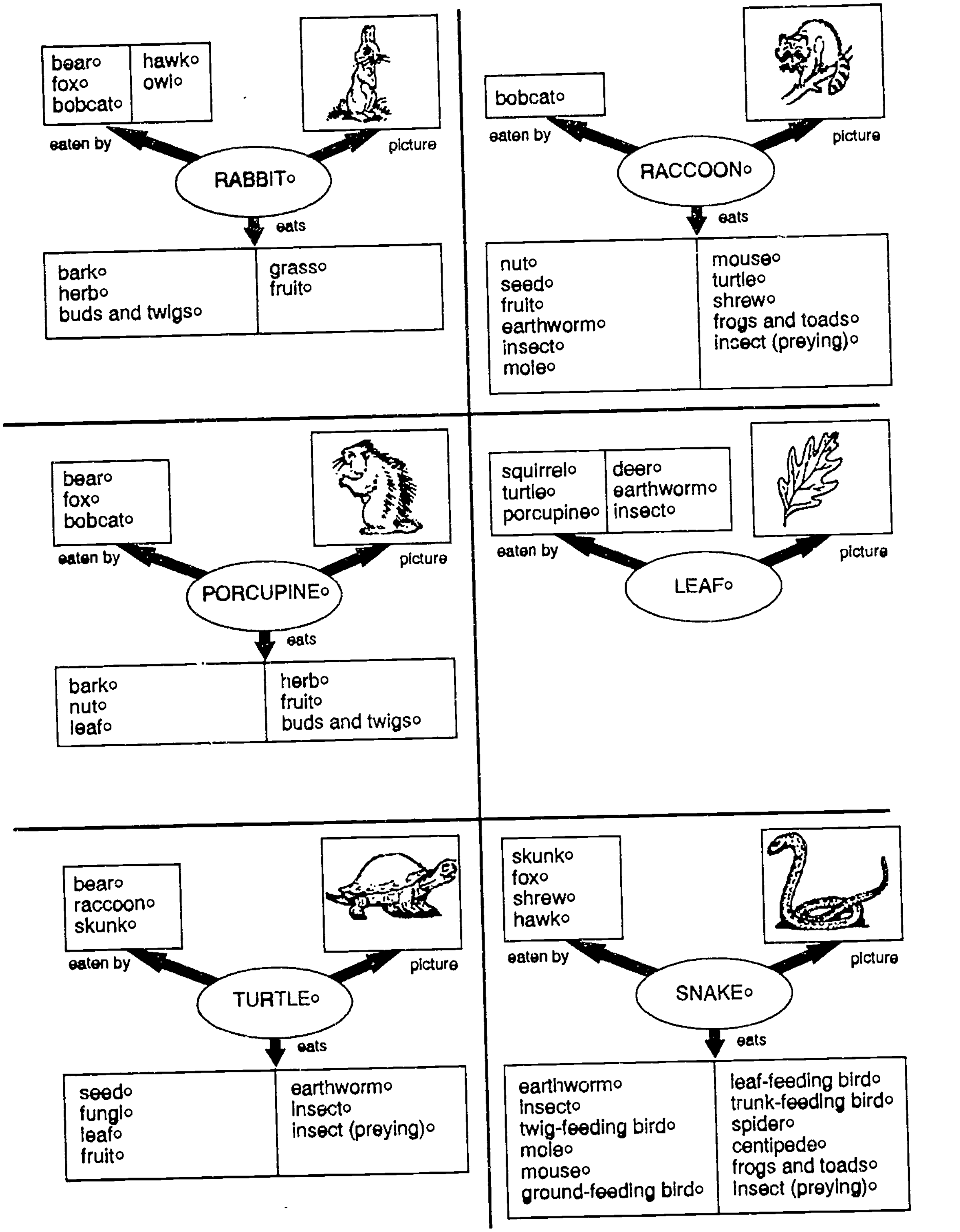
These students are Liberal Studies majors (prospective elementary school teachers), most of whom are in their senior undergraduate year. They are ethnically diverse and about 80% female. They have nearly all studied biology previously (1–3 courses), but about half have never touched a computer before.

The inquiry-based class aims to give students experience in *doing* "science" and interpreting the results, to help students overcome their fears and phobias about science, and to give them a package of lab activities that they can adapt for and conduct with elementary school students. Many (perhaps most) actually learn to like science in this classroom and they gain a fairly good dose of computer literacy as well.

Students engage in such activities as growing kidney beans, observing the life cycle of mealworms, dissecting flowers, stimulating the effects of natural selection on competing populations over successive generations, and studying five human body systems (circulatory, respiratory, digestive, urinary, and male and female reproductive) in various ways.

Students use SemNet to organize their knowledge about each topic of study. An underlying assumption is that the process of organizing ideas in the computer prompts and supports an individual's own personal or cognitive knowledge construction. Our research suggests that many low aptitude students are lacking the basic skills involved in systematic knowledge organization (such as linking parts with a whole or linking concepts of a certain class to a superordinate concept). SemNet allows us to provide explicit instructions about and modeling of key knowledge organization skills and also provides students many opportunities to practice with feedback.

Enter Data into SemNet®



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Our research also suggests that collaborative knowledge construction is much more powerful than working alone or in pairs. My students typically work in groups of four. Each member of the team becomes a specialist in one area of a topic and is responsible both for entering that information into the net and for teaching it to others. Intense meaning negotiation and peer tutoring result. Having frequent opportunities to review work by other student groups also is important in enlarging students' views of what is possible.

Representations of Motion in Physics

Suzanne M. Lea, University of North Carolina at Greensboro

Tests are given to measure student knowledge for one of two purposes: to compare it with the student's previous knowledge or with the knowledge of other students and to diagnose student learning problems and provide remediation. The former type of test is common. The latter type is rare, but promises to improve instruction. However, it requires either small class sizes or technological assistance. The motivation for the present work is an interest in developing computerized tests of student conceptual understanding. Achieving this goal requires that answers to test problems be represented in a way the computer can easily interpret. In our case, answers are represented as manipulable graphics symbols on the computer screen.

We investigated representations of motion in the context of kinematics and dynamics in physics, with the eventual aim of determining the best representation for computerized testing. The representations studied were verbal descriptions, formulas, graphs, vector diagrams, and "strobe diagrams": the graphic equivalent of strobe photographs. The investigation may also determine what representations students understand most easily (with obvious implications for instruction).

The study consisted of a set of three interviews with student volunteers from three introductory physics classes at The University of North Carolina at Greensboro: calculus-based (four students), algebra-based (six students), and Workshop Physics (Laws, 1990, 1991) (four students). The first interview asked students to compare the accelerations of two balls moving down u-channel tracks with the same slope but different widths. The difference in rolling radius causes the ball traveling in the wider track to have the smaller acceleration. The demonstration was set up so that students could compare qualitatively the changes in velocity of the two balls over the same time interval. The second interview asked students to compare the accelerations of two blocks of different mass being pulled across a table by spring balances displaying the same constant reading. The third interview asked students to think aloud about how to solve physics problems from kinematics and dynamics. The problems were deliberately made ambiguous to discover whether students would realize they must make assumptions to solve the problems.

The interviews have just been completed, and the analysis is only beginning. The type of analysis appropriate for this investigation is descriptive rather than numerical. The number of students involved is too small for valid statistical analysis. However, the study can identify common difficulties students have and indicate where statistical studies would be fruitful. Important indications of the causes of difficulties may be obtained by the analysis of a few in-depth interviews, whereas the large sample size required for statistical validity precludes in-depth probing.

Preliminary analysis indicates that we reproduce many earlier results: failure to distinguish between velocity and acceleration; beli-f that a

constant force applied to an object will cause it to move at constant velocity; belief that formulas cannot be used for qualitative comparisons, but are useful only when numbers are available to substitute into the formula; and failure to distinguish position–time, velocity–time, and acceleration–time graphs: either all three were parabolas or all three were straight lines.

We find from this study that many students understand strobe diagrams more easily than other representations of motion, possibly because the diagrams look like the physical motion. Strobe diagrams are almost totally absent from both textbooks and laboratories; the spark timer and the Physical Sciences Study Committee bell timer have been replaced by sensors that feed data directly into the computer, producing graphs. We find that Workshop Physics students understand graphs much better than other students in the study, but that their understanding was not useful to them in solving problems.

We find that none of the students in the study had any experience outside physics class or laboratory with constant nonzero net forces. Students encounter kinesthetically only forces that start an object moving and then decrease to make the net force zero, so that the object moves at constant velocity. They extrapolate this experience to all constant forces, leading to ingenious arguments intended to reconcile Newton's second law with their intuitive notion that constant force means constant velocity.

A partial analysis has been done for two students thinking about the following problem:

- A Porsche accelerates from 0 to 60 miles per hour (26.8 m/s) in 5 seconds. If it is started at one goal line of a football field, could it get to 60 mph before reaching the other goal line? (Football field goal lines are 91.44 meters apart.)

The first student exhibits a good understanding of velocity and acceleration and a good ability to solve problems. However, he does not realize he has made assumptions while solving the problem. (Three major assumptions are made: that the measured acceleration of the Porsche does not change when it is driven on the football field; that the car travels in a straight line down the field; and that the acceleration is constant.) The student does not appear to recognize that the equations he uses are restricted to the case of constant acceleration.

The second student is unable to solve problems in the interview context because she has not completely differentiated the concepts of acceleration and velocity. She is unable during the interview, even with repeated probing, to make a statement such as "if an object is accelerating, its velocity is changing." All her criteria for recognizing accelerated motion involve distances. She is not a poor student; she makes respectable grades in other technical courses, and she currently has a C average in her physics course. However, her conceptual difficulty, if not dealt with, may prevent a major in physics.

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Transcript (Partial) of Two Student Interviews Solving Kinematics Problem

- Problem: A Porsche accelerates from 0 to 60 miles per hour (26.8 m/sec.) in 5 seconds. If it is started at one goal line of a football field, could it get to 60 mph before reaching the other goal line? (Football field goal lines are 91.44 meters apart.)

Students were asked to think aloud about how they would solve the problem. They had a printed copy of the problem to refer to while thinking. Students are identified by code names.

Bravo Charlie, 10-30-92

Male, age 23, has bachelor's degree in economics, taking courses to prepare for a second bachelor's degree in textile management; taking algebra-based physics because it's required for his proposed major.

Interviewer (I): describe the motion of the Porsche.

Subject (S): Describe the motion—starting from rest, velocity 0 m/sec., as it moves down the field it should increase its velocity it should accelerate in the given distance of the football field.

I: How would you go about solving the problem?

S: Oh lord—ok—first thing I'd do would be writing down my given information in that, uh, it's that for, uh, it accelerates 28 m/sec. in 5 sec. and from that you should be able to figure out an acceleration for 1 sec. Since you don't have that as a figure for acceleration you probably go to one of the formulas that are derived from time and distance problems, just guessing probably some variation of x =1/2 a t-squared plus v - 0 times t-squared + v - 0 I think it is. Oh, you know, you end up going to one of those equations to find something or help me to find the answer I'm looking for.

I: Ok, so you have enough information to solve for the acceleration and then you'll use one of these four equations that you'd have.

S: That's how I'd begin solving it.

I: And what would you look for? What are you solving the equation for?

S: Well, that's where for me personally it helps me to have the four equations in front of me either written out or in memory or given.

I: I'll write them down for you.

S: Since I don't have to take the MCATs I'm not planning on putting them in my memory, it's something I can go refer to later on. Ok.

I: I wrote down several equations that might be—

S: Looking at this, what it's asking me is can it get to 60 mph before reaching the other goal line, so you're looking for, uh, with that in mind I'm looking for an equation that's going to give me the velocity at the end of the football field. Based on that I'd probably start looking, uh, for the v-squared = v - 0 - squared + $2ax$ because you have an acceleration, you have a total distance, and you have the initial velocity, then you just solve for v-squared.

I: Ok, all right, and suppose that number you get is less than 60, what does that tell you?

S: It tells you that something's wrong with the engine so the Porsche can't make it. In general, the acceleration isn't great enough to get it there, so to get it to whatever speed you're looking for, to find by the end of the football field.

I: Ok. It might not be something wrong with the engine though, it might be—

S: It could be it's just not powerful enough, it tends to, it would seem to me
a Porsche is powerful enough to get there, so—

I: Certainly it can get there; the question is whether it travels further than the football field.

S: Mmmh.

I: How did you know that you were talking about two separate motions here, that you were talking about accelerating from 0 to 60 in 5 sec. and talking about moving the length of the football field?

S: How did you know you were talking about two separate motions?

I: Yes

S: Uh, that's an interesting question, uh...

Caribbean, 10-28-92

Female, 37 years old, physics major, taking calculus-based physics; has a C average; made a B in Introduction to Computer Science course.

I: Describe the motion of the Porsche.

S: The Porsche is just increasing in—it's accelerating from 0 to 60; therefore the acceleration is increasing over a period of 5 sec.

I: You said the acceleration is increasing?

S: Mmhm. If you drew an acceleration graph it would look like—oh, let's see. It's more like that. If it started at 0 down here, it's getting up to 60 over here after 5 sec. Actually, that should

be 60 and that should be 5. It started at one goal of the football field and we want it to reach the other goal line and it tells us the field goal lines are 91.44 m apart.

I: Can you think a little bit about how you might start solving this problem?

S: Well, it's not necessarily the right way; it's just a way to start. It gives me an approximation because that's only going to come out to be about, less than 4. It's going to be approximately 3 something. And it's going from 0 to 60 and 26.8 m/sec. is 60 mph and it went there in 5 sec. And I could pull the average m/sec. I suspect by dividing 60 mph by 5; that'd be about 12 mph, and I want to set that up with a ratio.

I: What happened to the seconds on the bottom of that last calculation?

S: 5 sec. Actually, I should convert sec. to min. or hr.

I: What kind of number is that 12. Is it a speed, or an acceleration, or what is it?

S: It would just be speed, an average approximate speed. It's just kind of a weighted average. Across, but ...

I: What is the weighting? Explain more about this weighted average to me.

S: Well, you've got 5, here you're at 0, and here you're at 60 mph. And this is over 5 sec., the time, and I know that I'm at 0 here and I know that I'm at 60 mph here. So if I divide the 5 into the 60 and come up with 12, then I can approximate that it went approximately 12 mph per sec.

I: Ok, and what does that mean, 12 mph/sec.?

S: Well, that means in approximately one of these time periods, that it would have gone, at any given point it was accelerating at a different speed between 0 and 5. And what I'm trying to do is just get an approximation of how many mph it was going in approximately 1-sec. period of time so that I can see if it would reach the end of the football field or if it's going to run out of space and crash into the wall over there. Because from here I notice that it's not going to have time if it was going at 60 mph—if it started at 60 mph and maintained a constant speed, it would have run into the wall.

I: Ok, and you know that why?

S: Because at 26.8 m/sec., which is 60 mph, will not divide into the length of the football field which is 91.44 m, it won't go in there 5 times. So it doesn't have 5 sec. and it will smack the wall.

I: If it's accelerating from 0 to 60, do you have any idea about what size an average sort of speed might be?

S: Hmm. Well, that's sort of what I'm doing here, is getting kind of an average speed. It's very rough because at, it could be at 0 or at 1 or at 60 together. But 12 mph/sec. is approximately the average speed.

I: So that's—when you say there, you're talking about where you divided 60 by 5 sec.

S: Yeah.

I: That gave you a sort of average speed?

S: Right, and then if I did see that's 60 mph, I could divide 60 into 26.8 m/sec. and...

I: And why are you doing that?

S: Well, that would give me what 1 mph would be equal to so many m/sec. Then I could multiply that by 12.

I: So you're just changing the 12 to m/sec.

S: Yeah.

I: Ok. Suppose we have that number.

S: Ok, If we have that number, then we could just multiply by 5 and see if that number was smaller. It would need to be less than or equal to the 91.44 m. If it did, the car could have made it, otherwise it hit the wall.

I: Well, is there any way you could make an estimate of how large that number is that would convert the 12 into m/sec.?

S: Mmm. Yeah. You can just take and divide 60 into 260 which is about, I guess 4 x 6 is 24, so it's going to be a little larger than 4 m/sec.

I: And that 4 is 60 divided into?

S: 26.8 m/sec. And then since we're going approximately 12 miles, multiply that by 12 and get 48, that's right, and multiply that by 5 and you'll get 245 m. Those are seconds, they cancel.

I: Do you know any equations that might apply to this problem?

S: Umm. I'm sure there're a bunch of them in the book, but right off the top of my head I don't.

I: I'm going to write you four equations that are related to what we've been talking about in these interviews. Do any of those look like they might be helpful?

S: Oh, yeah, we don't need force = mass × acceleration. We don't even know the mass. Or the force. We don't need the third equation. And, because the velocity initially is 0, both that one and that one are going to give us 0 for the first number, and I suspect the first one is the most useful one. ($v = v - 0 + at$).

I: Ok. The first one is...?

S: $v = v - 0 + at$ and in this case $v - 0$ is n and your acceleration is 26.8 m/sec. and you've got 5 sec.

I: Ok, now you've said the acceleration is 26.8 m/sec. How do you know that?

S: It told me so! It said it's 60 mph. and we've got an initial—

I: Is 60 mph an acceleration?

S: Not really. Yeah, it is. m/sec. ... I would say it is. It may not be, but I would say it is.

I: Ok, so the thing in your car measures accelerations.

S: It's as close to instantaneous acceleration—well, actually it measures speed, but frequently there is a difference between speed and acceleration, but if you're traveling down the highway at 0 mph and you look down, that's as close as you're ever going to get to about, to actually seeing instantaneous acceleration. But frequently speed is used as acceleration, or acceleration is written as speed. But they are slightly different. Speed is a scalar quantity if I remember right, and acceleration is definitely a vector quantity. It has a direction.

Bravo Charlie, 10-30-92

[Partial transcript for first student looking at two different masses being pulled by spring balances across a table.]

I: So the reading will be steady after you have gotten things started moving. And what will happen to the velocity?

S: It should move at a constant speed, I would say.

I: No matter how hard you pull with the spring balance?

S: Well, providing you're pulling with a constant force, it should be moving with a constant speed. If you changed the force, that would change the speed.

I: What force is being measured by the spring balance?

S: It's going to be measuring the net force.

I: How do you find the net force?

S: You would have to figure out the force applied to it, Uh—the net force equals the applied force, the pull, minus the friction, in the opposite direction. You'll have to figure out the applied force, get a number, and know the coefficient of friction.

I: Do you know any equations that apply to objects when you pull on them?

S: Mmm ... When you pull on them ... Well, the best way to describe it is not any tried or true formulas, you have to analyze each situation and make your own, is the best way to describe it. I could probably come up with something depending on the situation.

I: Have you talked at all about Newton's laws in class?

S: Yes we have.

I: Do you remember Newton's second Law?

S: f = mass × acceleration

I: Does that equation help you in any way to compare the motion of these two objects if you pulled them with equal readings on the spring balance?

S: What we're looking at is f - net = ma, so what you need to find is the net force, which is the force your pull minus the force of friction, so that's going to be what you're dealing with. You could get it constant. Now, uh ... I'm struggling with the spring and trying to compare that with the usual notion of applying force by a push, rather than a pull. And you're ... I'm trying to reconcile the idea that the net force is

given by the spring scale with ... That's something I've worked with before ... I want to say just pulling on the spring scale will give me the total force of the pull, but then I have to go and correct myself, saying it's going to be the net force. We should be able to figure out something here just using the scale. It's that kind of thing I'm having to resolve, working with the spring scale and figuring out exactly what each force is.

I: What does acceleration mean about the motion of an object? Describe its motion.

S: The way I describe acceleration is that it's a change in velocity for, over a change in time. In problems, I think of it as units: m/sec.-squared. What that means to me is that you have a velocity of m/sec. for every sec. That tends to help me think about things a whole lot.

I: In this situation, the equation tells you there's an acceleration. Is the velocity of either block changing?

S: Hmm ... uh ... In a sense, yes. Ask the question again. That's kind of a confusing question.

I: Ok, what you've told me is that, if they have the same spring balance reading, one has a bigger acceleration than the other, although they have the same net force, you've told me. And the more massive object has the smaller acceleration. And you told me an acceleration meant that their velocity was changing.

S: Right. What we're leaving out here again comes back to friction, at least in my mind. There was a great question on the exam that said in free space, you're having a force on it, because there's no other force acting on it. The velocity at different point is going to keep increasing because there's always that acceleration. It then went on to say that an opposing force equal to the initial one came from the opposite direction. The answer, which I got correct, was the object in free space would keep moving at the same speed when the second force was applied. So bringing that to this problem, where the friction is applied again, you have to have that acceleration to keep the net force, to keep a constant velocity.

I: Are you telling me that whatever pull you put on it is exactly balanced by friction.

S: To some degree, yes. It's balanced out in the net force. You're pulling on it and you've got to keep having the acceleration by definition, and the friction on it will keep it at the constant velocity. It's not going to keep accelerating to a faster speed. So yeah.

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Assessment and Evaluation as a Means to Enhance Learning

Jose P. Mestre, University of Massachusetts—Amherst, Chair

Panel Members: Barbara S. Beltz (Wellesley College), Bonnie J. Brunkhorst (California State College, San Bernardino), Audrey B. Champagne (SUNY at Albany), Angelo Collins (Florida State University), M. Kathleen Heid (Pennsylvania State University), Doris R. Helms (Clemson University), David Hestenes (Arizona State University), Don Kirk (San Jose State University), Maxie Kohler (The University of Alabama at Birmingham), Ivan Legg (Memphis State University), Francis Lutz (Worcester Polytechnic Institute), Pamela Mack (Morgan State University), Maynard Miller (University of Idaho), Patricia L. Samuel (Boston University)

Introduction

Assessment in the sciences and mathematics is undergoing major reform. Several factors have conspired to make this reform inevitable. First, a mounting body of cognitive research on learning and problem solving over the last decade and a half has helped us understand the salient attributes of skilled problem solving and scientific reasoning. In turn, this body of research has allowed an informed scrutiny of assessment practices in the sciences and mathematics to ascertain whether they reflect the kind of reasoning and problem solving employed by scientists. This scrutiny has led to the realization that most standardized achievement tests in math and science assess factual knowledge rather than scientific reasoning or problem solving (Harmon and Mungal, 1992a, 1992b; Murnane and Raizen, 1988; Resnick and Resnick, 1992).

The six short papers that follow describe different assessment strategies emerging from the reform movement in the sciences and mathematics. In her paper, Angelo Collins argues that the format used for traditional assessments may not be optimal for testing "what is worth knowing" in the sciences and mathematics. She overviews the main ingredients composing "alternative" assessments and then describes one type of alternative assessment, portfolios, in more detail. More specifically, she overviews what constitutes a portfolio, how it differs from a "scrapbook," what material belongs in a portfolio, how to decide whether there is too much or too little material in a portfolio, and finally how to grade a portfolio.

Audrey Champagne discusses group assessment, its advantages as both assessment and

instructional tools, and the psychological and practical rationales for group assessments. She begins by identifying three stages of group assessment. She then discusses what can go wrong with group assessment, the benefits to students and teachers, standards for assigning grades to individuals, groups, and entire classes, and the teacher's role in administering group assessments. She also argues that group assessment blurs the line between assessment and instruction and reflects better the type of problem solving required in industry.

Kathleen Heid considers the role of technology in mathematics education and argues that technology offers the option of spending more time on analysis and thinking, and less time on computational drudgery. She describes a new algebra curriculum called *Computer-Intensive Algebra* (CIA) that is designed to exploit both recent knowledge about teaching and learning and the growth in the access students have to computer technology. She then discusses how the assessments that accompany the CIA curriculum were designed to highlight the type of analysis and thinking expected of students. Heid also discusses the new role of teachers as facilitators within a computer-intensive curriculum and the support necessary to empower teachers in serving as collaborators with students.

Doris Helms reviews three different assessment strategies currently being used in the biology program at Clemson University. The first strategy employs free-response essay questions in large biology lecture courses designed to probe students' ability to handle data, solve problems, and integrate concepts. Helms also discusses grading strategies for essay assessments. She then argues that essay assessments also serve as a tool for teaching students the value of clear, focused, well-organized writing. In the second assessment strategy, Helms describes a technology-driven kiosk placed in the Student Union building that administers an ecology quiz to any interested student. The data collected from hundreds of students who took the quiz were then used in designing instructional strategies for teaching environmental issues in the freshman biology classes; in particular, instructors were able to identify prevalent student misconceptions and address them directly during the course of instruction. The third strategy described by Helms consists of using simulated investigative laboratories that assess students' ability to gather and analyze data and to formulate and test hypotheses.

The remaining two articles focus on alternative assessments in physics. In his article, David Hestenes begins by arguing that every science has *basic concepts* that must be mastered by students if they are going to gain other than a superficial understanding of the subject. Although scientists are aware of, and continually use, basic concepts, Hestenes states that the sciences lack instruments that assess understanding of basic concepts. He goes further and states that proficiency at quantitative problem solving is no guarantee that a student has achieved conceptual understanding. Hestenes provides strong support for this last statement by presenting extensive data from conceptual assessments designed by himself—students at all levels who demonstrated proficiency in problem solving and earned high grades in mechanics courses did quite poorly in his assessments of basic Newtonian concepts. He concludes his article with discussions of both how one should go about developing basic concept inventories across the sciences and what is the best way to use them.

Jose Mestre describes two types of assessments that he has used in teaching large introductory physics courses at the University of Massachusetts. Both assessment strategies are based on knowledge of effective problem solving gleaned from cognitive research studies and are designed to promote reasoning based on concepts, which is a salient attribute of expert behavior in the sciences. Mestre illustrates how the first type of assessment, the writing of qualitative strategies for solving problems, is also an excellent instructional tool. Strategy writing helps students form concepts by having them actively use concepts in different problem solving contexts. Mestre demonstrates how writing qualitative strategies probes understanding at a

level that is impossible to achieve with traditional problem solving tests. The second type of assessment evaluates students' ability to identify the principles that could be applied to solve problems, a skill that is also associated with expertise. Mestre provides data showing that students who wrote qualitative strategies as part of their course requirements were better able to select the principles that could be applied to solve problems than were students from a traditional course in which strategy writing was not required.

Despite the variety of topics and views in these six articles, common themes emerge across several of the articles. These themes are as follows:

- *It is often difficult to distinguish good assessments from good instruction.* Good assessments are tools for learning, not just tools for probing students' knowledge; as such, they allow students to be reflective about the depth of their understanding.
- *Good assessments can be used to inform, shape, and guide instruction.* Most achievement tests to which students are subjected are summative— by the time the student (or teacher) receives the results of the test it is usually too late to take any corrective measures to improve performance. Good assessments serve the function of supporting instruction by diagnosing students' understanding of important ideas at critical junctures, and thereby allowing teachers and students to make midcourse corrections to ensure learning.
- *Good assessments should reflect the type of reasoning and problem solving practiced by professionals.* Many traditional science tests simply measure recall of factual knowledge or mathematical prowess. Although factual knowledge and mathematical skills are indispensable ingredients in practicing science, they are not an accurate reflection of the type of reasoning needed to work as a scientist in academia or in industry. Good assessments should reflect the type of reasoning valued by scientists so that students strive to model it.
- *Assessments of quantitative problem solving do not necessarily measure conceptual understanding.* In quantitative disciplines such as mathematics, chemistry, and physics, traditional assessments tend to require mathematical manipulations that students can perform with minimal understanding of the concepts underlying the mathematics. There is a clear need to assess conceptual understanding in order to help students appreciate that a few powerful concepts can be used to explain a wide range of phenomena.
- *"Alternative assessments" emerging from the reform movement demand increasing amounts of qualitative reasoning.* The value of having students perform qualitative reasoning based on concepts is becoming clear— qualitative reasoning requires that students understand the underlying meaning of concepts. Ability to analyze problems conceptually before plunging into mathematical solutions alleviates the "I-don't-even-know-how-to-start" syndrome experienced by many students attempting to solve problems in the physical sciences.

The articles herein have highlighted how assessment can enhance learning. The important question now becomes, how do we introduce prospective science and math teachers to assessment reform, or perhaps more generally, how do we reform the education of prospective math and science teachers so that it reflects recent insights gained from research into learning and instruction?

Since teachers tend to model the same kind of instruction and assessment that they received in college, it would appear that the most efficient way to make inroads is to start at the college level. College instruction in the sciences and mathematics needs to promote the kind of instruction and assessment that we want prospective teachers to model when they become teachers. The emphasis given to factual knowledge and quantitative problem solving in current

assessment practices is short-changing the value of qualitative reasoning based on conceptual knowledge. We need to design tasks for use in homework and tests that emphasize the importance of conceptual knowledge in scientific reasoning. Only by emphasizing a more balanced mix of quantitative and qualitative reasoning in the assessments that we administer in college will we be preparing students to practice and teach science.

One way to remedy this situation is for college science and mathematics departments to hire experts in their own disciplines whose primary responsibility is improving undergraduate instruction. There are increasing numbers of individuals holding Ph.D.'s in the sciences and mathematics who are primarily interested in research and development directed at improving learning and instruction. Once part of the fabric of academic science/math departments, these individuals could perform numerous crucial functions, such as designing and teaching courses on pedagogy for prospective teachers, working with other professors in designing instructional or assessment strategies, and teaching seminars and workshops on pedagogy and learning for entering teaching assistants who ultimately become college professors. In short, the preparation of prospective teachers in the sciences and mathematics should not be left entirely to schools of education; scientists need to play a more proactive role in this endeavor.

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Alternative Assessment in Undergraduate Science Education, with Emphasis on Portfolios

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For decades, instructors of undergraduate science courses have refined "scientific" modes of assessing, evaluating, and grading student learning. Based on statistical principles, testing procedures have been developed that are very precise. However, in the past ten years, driven by the question, "What is worth knowing?" a new movement in assessment, frequently termed alternative assessment, authentic assessment, or performance-based assessment.[1] has been gaining prominence among those concerned with assessment in science.

Alternative assessment is not a single entity; rather it is a collection of modes of gathering data to describe what students know and are able to do. While these modes of data gathering share several characteristics, no one assessment possesses all the characteristics. Wiggins (1992,

1989), among the most thoughtful of the developers of authentic assessments, has developed lists of characteristics of such assessments. Some of the characteristics of alternative assessment tasks—characteristics that might have greatest impact on undergraduate science teaching and learning, especially when science is considered as a liberal art—include the following: Alternative assessments

- simulate the challenges and constraints facing those who do science or simulate tasks that require the use of science knowledge, skills, and dispositions in everyday tasks.
- are composed of "ill-structured" and non-routine challenges that require a repertoire of knowledge.
- contain contexts that are rich, realistic, and enticing—with inevitable constraints of time and resources.
- focus on the ability to produce a quality product or performance, rather than a single right answer.
- allow students to demonstrate strengths rather than probe for weaknesses.
- involve patterns of responses and behavior emphasizing habits of mind.
- have criteria that are known, understood, and negotiated as the performance proceeds.
- require scoring that focuses on the essence of the task and not what is easiest to score.

In the enthusiasm for alternative assessment in science, undergraduate instructors should not forget that some of the tasks that have a long-standing tradition in their science courses have characteristics of alternative assessment. Maintaining laboratory notebooks, writing laboratory reports in the style of professional journals, publishing student research journals, holding mock research conferences, and using lab practicals are familiar modes of assessment in science. Shulman (1988) warns that alternative assessments present a union of insufficiencies. Each mode of assessment, including the traditional multiple choice and essay question exams, has strengths and weaknesses. Shulman claims that it is possible to create an accurate profile of learning only when several modes of assessment are employed. The current emphasis on alternative assessment allows those who teach undergraduate science courses opportunities to examine the purposes for learning science, to re-examine existing assessment practices, and to design new modes of assessment.

Portfolios

One of the most frequently discussed modes of alternative assessment is the portfolio. Prior to 1988, research and development articles on the use of portfolios for assessment were relatively rare. However, a recent search of the ERIC data base located over 120 articles on portfolio assessment. While most of these articles are on the use of portfolios in assessing writing and performing arts tasks, portfolios are gaining popularity in science assessment.

A portfolio is a collection of evidence which constitutes a compelling argument that a student has become proficient at or is making progress toward a learning goal. Evidence related to a goal is one of the characteristics that distinguishes a portfolio from a scrapbook of mementos or a manila folder of unrelated material. Portfolios are an especially fruitful mode of assessment for capturing context, for highlighting change through time, and for allowing students to show off their personal strengths and talents.

Portfolio assessment requires instructors and students working alone and together to examine serious questions about learning science. Among the questions that need to be examined each time the portfolio process is used are the following:

- What are the goals for which evidence will be collected?
- Is a collection of evidence a reasonable way to demonstrate that goals have been met?
- Who is determining the goals—instructor, student, or both?
- What will count as evidence?
- Are there opportunities to produce and gather evidence?

- Which evidence will be required and which will be elected?
- How much evidence will be included in the portfolio?
- How will the portfolio be used?
- How often will the portfolio be reviewed?
- Who will review the portfolio?

As there are no correct answers to questions such as these, the answer that is negotiated gives each portfolio development process a local, contextual flavor. Struggling with the answer to such questions provides a focus for discussions on what science is worth teaching and learning.

Goal

Making decisions about the exact development of the portfolio in a local context does not mean that there are no guidelines for portfolios. The paramount requirement is that the portfolio be a collection of evidence. The instructor must decide what goals of the course are best met by evidence collected over time by the student. An instructor might state several goals from which students select one or students might craft individual learning goals. Becoming proficient at representing science data in graphic form might be an appropriate goal for an undergraduate science portfolio.

Types of Evidence

Four classes of evidence have been distinguished: (1) artifacts (materials usually produced in the course such as notes, tests, and lab reports); (2) reproductions (materials produced in the course but often not captured, such as raw data or first drafts of reports); (3) attestations (materials produced by others, such as thank you notes for out of class work or acknowledgments that parts of the work—figures, for example—were done by someone other than the author); and (4) productions (materials produced especially as evidence for the portfolio). There are two major types of productions, captions and reflections. A caption is a statement attached to each document that states what it is, what it is evidence of, and why it is evidence. Post-it notes serve this purpose well. Captions are useful for students who are developing portfolios as well as for the instructors who evaluate them. Without a caption, a lab report is a lab report, but with a caption it may become evidence of learning how to separate evidence from inference. The reflective statement is usually written near the end of the portfolio development process. It helps the student and the instructor look critically at the accumulated documents as evidence of learning.

Although the term document has been used to identify the collected evidence in a portfolio, evidence need not be limited to written documents. Photographs, sketches, videotapes, journal and diary entries, and models may all serve as evidence.

How Much Evidence

While one piece of evidence is not enough to constitute a portfolio, putting all work samples into a container is not a portfolio either. Portfolios are equally boring and unconvincing when they hold too little and too much evidence. While too little evidence might indicate incomplete work, too much evidence might indicate a lack of clarity about the goal or an inability to judge the quality of one's own work. The use of the value-added principle has proven useful in determining how much evidence to include. The accumulated evidence is gathered. Then the most compelling piece of evidence about the goal is set aside. Then the question is asked, what value would be added to the portfolio if another piece of evidence is added? A limit is quickly reached. It is usually helpful to survey the remaining evidence after the limit has been reached to make sure that no compelling evidence is overlooked.

Concurrent with the decision of how much evidence to place in the portfolio is a decision about how to organize that evidence. This is not a question of display but of constructing a compelling argument. While there is no single

correct organization, chronology, potential power to convince, class of evidence, and theme have all been used as organization principles.

Two final activities bring the portfolio process to completion. One is requiring students to prepare a table of contents that leads the assessor through the evidence. The other is to have the students engage in peer evaluation of their portfolios by asking one another if they are convinced by the form and substance of the collected evidence.

Rating

Rating portfolios is a process that requires a holistic examination of the accumulated evidence and calls on the professional judgement of the person rating the portfolio. Two modes of portfolio rating are emerging. One requires that the assessor prepare guidelines, called rubrics, in advance. As portfolios become a more common mode of assessment, examples of acceptable, compelling portfolios will make the preparation of rubrics an easier task than it is currently.

Another rating system requires two types of judgement: against technical criteria and for substance. The technical criteria usually require yes/no choices and relatively easy decisions. As questions, the technical criteria become as follows: (1) Is there a goal statement? (2) Is there a rationale for the goal statement? (3) Is there a guide that helps the assessor find his/her way through the evidence? (4) Does each piece of evidence have a caption that states what the document is and why it is evidence? (5) Is there a final reflection? (6) Are all prescribed pieces of evidence present? (7) Is there variety among the evidence? And, (8) has all redundant evidence been removed?

The issue of substance relies on professional knowledge and translates into two questions: (1) Is the assessor convinced by this collection of evidence that the person who has developed the portfolio has achieved or made progress toward the goal? And, (2) if not, what additional evidence would be needed to convince me? The amount of additional evidence forces a judgement on the worth of the portfolio and contributes to a profile of what the student has learned in a science course.

Notes and References

[1]While frequently used interchangeably, there are differences among the three. Alternative assessment seems to mean any assessment task that is not a traditional paper-and-pencil objective or essay question; performance-based assessment implies that the student must do something besides write a correct answer to a question; authentic assessment implies a high degree of fidelity between the assessment task and the practice of the discipline.

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Assessment in Groups: A Strategy for Improving Science Learning

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Engaging students in group assessment activities is a powerful strategy for improving science learning. This brief paper describes a procedure for group assessment, discusses the teaching

advantages of the procedure, and briefly reviews the psychological and practical rationales for group assessments.

The group assessment strategy proceeds in three stages. First, students write individual responses to an assessment exercise. Then a small group, two to four individuals, works to develop a more complete and accurate response to the exercise. Finally, under the teacher's direction, the class composes a response. This strategy is consistent with evolving cognitive research and is responsive to business and industrial leaders' demands that schools produce graduates with the interpersonal skills necessary to work productively in groups and who can assess the quality of their own work.

Achieving conceptual change through social interaction with adults and peers is a long standing theme in social psychology. The Russian psychologist, L. Vygotsky (1986), proposed how the development of scientific concepts occurs in young people through interactions with adults. This idea has been extended to classrooms where, under the guidance of a teacher, interactions among peers with slightly different levels of reasoning facilitates development of more sophisticated reasoning among the less sophisticated peers (Champagne and Bunce, 1991).

Contemporary social psychologists are providing empirical support for Vygotsky's theory: Conceptual understanding is enhanced when students work together in small groups on complex intellectual tasks (Brown and Ferrara, 1984). The mechanism by which conceptual understanding is enhanced is straightforward. When the task is to collaborate on an answer to an assessment task, students communicate their scientific ideas, defend, and evaluate their individual responses against those of their peers. In the process, assumptions underlying responses are brought to light and evaluated, factual information validated, and the logic of arguments assessed. Students' individual responses are strengthened and elaborated in the process and consequently, individuals' conceptual understanding improved. In addition, students' ability to communicate scientific ideas and to assess other students' responses improves. When the capacity to assess other's work is internalized the student can apply it routinely to evaluate his or her own explanations. The ability to assess one's work is a valuable intellectual asset requiring understanding of what performance is expected as well as the criteria on which performance will be judged.

The teacher's role in conducting group assessment is multifaceted. The teacher models exemplary communication of scientific ideas, and forms of logical argumentation. The teacher instructs students in scientific rules of evidence, sets standards of quality, and monitors students' performance as they perfect the processes through practice.

For all the potential the process holds there are ways in which it can go wrong. For instance, a student with a strong group presence and weak scientific knowledge and intellectual skills can be detrimental to the group assessment process. Thus not only does the teacher have the task of modeling scientific reasoning but also has the additional responsibility of educating students in functional group behavior.[1]

The benefits to learning of group assessments are great. Engaging in the process is in itself a learning experience for students. In addition, the process is informative to the teacher. Careful attention to small-group discussion and the characteristics of the whole class' response to the assessment exercise provides the teacher with important information about how much of what the teacher expected the students to learn was actually learned. This information is valuable in planning subsequent classes.

In fact, the benefits to learning are so great that critics observe that such activities are teaching, not assessment. The counter comment is that it is difficult to distinguish good teaching from good assessment. In either case, students are engaged in an intellectually challenging task from which they are expected to learn. In the case of group assessment, however, engagement in the exercise comes after teaching and often the

information collected by the teacher is used to assign a grade.

Either the product, the answer to the assessment exercise, or the process by which it was produced can be used to assign grades. The assignment of a grade on the basis of group assessment requires some careful consideration regarding what is being assessed and consequently the data that will be evaluated to assign a grade. The assessment strategy described above results in three types of products, individuals' responses, small-group responses, and class responses. When the teacher's goal is to assign a grade to an individual that reflects the individual's attainment of subject matter understanding and reasoning, the grade can be based on the individual's attainment in comparison with that of the class. In other words, the class-generated response is the standard for the individual student's grade.

Assigning individual grades using the product of the group requires more analysis. One principle is to divide the credit for the response among the individuals in the group. Application of this principle does not necessarily mean lower grades because the group product should be of higher quality if the group is working well together. However, a complication arises because it is difficult to know if all students contributed equally to the product. One way in which to address this complication is to ask the members of the group to decide if they all contributed to the group product or if the grades of individuals should reflect the importance of their contributions to the response. The class' response can be used to assign grades to the individual applying the same reasoning as applied to the group process. However, the grading process is made more difficult by the numbers of the individuals involved.

Grading can serve other functions as well:

- When the teacher's primary goal is development of groups that work well together, individual grades can be assigned based on the quality of the group response without consideration for individuals' contributions.
- The class product can also be used to assign "grades" to teachers. The grade is a measure of the comparison of what the teacher hoped to achieve with what the class actually achieved.
- Process rather than product can also be the basis of grades. The process indicator depends on the quality of the individual's participation in the group, and can be based on criteria such as oral communication, ability to listen when others are speaking, and ability to identify points of disagreements and facilitate their resolution.

There are many barriers to implementation of group assessment of which the necessity of assigning individual grades is the most serious. As the previous discussion suggests, some of the concerns are simply a matter of sorting out what is being assessed and how credit will be assigned. Assessing the quality of the individual's participation in the group is a resource-intensive process requiring observation of the group as its members engage in the task. It is also difficult to get interrater reliability on observations of this type. There are also underlying philosophical barriers to group activities in school and university classrooms. While industry and businesses extol the virtues of cooperation in the workplace, the competitive spirit and valuing individual attainment are the prevailing philosophy of formal education.

Other barriers are equally challenging but more practical than philosophical in nature. The physical arrangement of lecture halls and the size of classes are formidable barriers to assessment in groups. However, identifying ways to overcome these is well worth the effort because of the potential for the process to improve achievement. Group assessment provides students the opportunity for intellectual activity that produces conceptual understanding. For the teacher, observing students engaging in the process provides valuable information which can be used to plan instruction. Assessment in groups also is a response leveled at education by business and industrial leaders that the activities

of school and university classrooms are conducted so differently from those in the world of work where tasks are assigned to groups and resources available to aid in the completion of the tasks. Only in schools and institutions of higher education are individuals constrained to work alone and without external resources.

Notes and References

[1]Cooperative Group Learning is a popular strategy for teaching students how to work well in groups. Its primary purpose is training cooperative behavior in groups, not the content (subject matter and reasoning processes) to be learned. The cooperative group process is highly routinized. Students are assigned specific tasks and are evaluated on how well they perform the group tasks and contribute to the successful functioning of the group.

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Computer-Intensive Algebra and the Computer-Intensive Mathematics Education Institute: Implications for Mathematics Faculty about Assessment as a Means to Enhance Teaching and Learning

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Assessment and evaluation have always been an essential part of the teaching and learning of the scientific disciplines. Mathematics and science teachers at all levels have long been interested in how well their students have been learning, and in the degree to which their particular courses and curricula have succeeded. For many of us in the past, the issue of assessment has been a fairly settled issue. We taught what we thought students should learn, we tested them on what we taught (through in-class or take-home testing, through course tests or comprehensive examinations), and we made some conclusions about the course, about the curriculum, or about the students, based on how accurately the students answered our questions. Sometimes, depending on how well the test results corroborated our other impressions, we made conclusions about the test itself.

At this point in the last decade of the 20th Century, we know more than ever before about the teaching and learning of the scientific disciplines, we are on the verge of redefining what is fundamental in introducing students to our disciplines, and we are beginning to learn of a variety of different ways to know more about what our students are understanding. Based on this new knowledge about mathematics education, the National Council of Teachers of Mathematics (NCTM) *Curriculum and Evaluation Standards for School Mathematics*, and the related NCTM, Mathematical Sciences Education Board, and Mathematical Association of America documents on teaching, learning, curricula, and evaluation, have resulted in a national dialogue and (some would say) a national consensus on the nature of teaching and learning of school mathematics at the beginning of the 21st Centu-

ry. In light of these recent and tremendous advancements in the teaching and learning of the disciplines, we can and must do more than use the traditional array of in-class or take-home tests to assess what we are teaching and what students are learning. We can and must find ways to use assessment and evaluation as a means to enhance learning. I will address some of the assessment and evaluation issues, by describing our experience with the creation, development, pilot testing, and assessment of an innovative technology-intensive beginning algebra curriculum, *Computer-Intensive Algebra* (CIA).

The Case of Computer-Intensive Algebra

Computer-Iniensi'ye Algebra is a curriculum that attempts to respond to the significant opportunities that technology has placed at the door of the mathematics classroom in the past 10 years. Coupling knowledge of the weaknesses of the current algebra curriculum and a commitment to capitalize on the explosive growth in the access students had to computing technology, Jim Fey (in 1985 at the University of Maryland) initiated the creation of *Computer-Intensive Algebra,* a fundamentally redefined beginning algebra curriculum. Work continued on that curriculum at the University of Maryland and at Penn State through the subsequent six years, resulting in a curriculum that assumed constant access to computing technology and that placed in center-stage roles the concepts of function and families of functions, the use of a variety of strategies and tools for representing and analyzing functions, and the notions of mathematical modeling.

In 1985, and still today, the current school algebra curriculum not only focused on questionable goals but also did less than an adequate job in addressing those goals. Students emerging from the traditional introductory algebra experience were unable to use algebraic ideas to help them understand the world around them and had a tenuous understanding of fundamental algebraic concepts. The traditional curriculum was (and is) driven by a need to master paper-and-pencil algorithms and takes little real advantage of current technology. Even the recent openness to incorporating graphics calculators in precalculus mathematics classes has resulted in curricular add-ons to enhance the attainment of old goals rather than fundamental rethinking of the goals and ways technology can be used to help us attain those goals. The existence and availability of computing technology suggested that the algebra of the future has to be based in new goals and in new content the adoption of which would require new ways to assess teaching and learning.

The first problem to be confronted in the creation of *Computer-Intensive Algebra* was the identification of the new content. The question to be answered was "What algebraic ideas are still important when students have access to computing tools that graph functions, fit data to function rules, generate tables of numerous varieties, and perform common symbolic manipulation (such as equation solving and simplification of expressions)?" The result was a curriculum whose major curricular themes were mathematical modeling, functions and families of functions, and tools and multiple representations.

The curriculum was designed to differ significantly from traditional curricula in a variety of content and pedagogical ways. Instead of the traditional approach of relying on paper-and-pencil calculations with occasional use of calculators, CIA exploited computing technology for routine calculations. Instead of the traditional use of word problems to illustrate the by-hand algebraic techniques, mathematical modeling became the *raison d'etre* for exploration of algebraic topics. CIA replaced the traditional emphasis on by-hand symbolic manipulation with an emphasis on the development of symbolic reasoning. Instead of concentrating on mastery of one technique at a time, the CIA curriculum emphasized multiple strategies and representations (graphical, numeric, symbolic, and situational). Teaching within the CIA classroom emphasized cooperative groups and extended work with real-world situations. For example, one problem in the second chapter of the CIA

text involved students with analyzing a business situation which is described by a linear demand curve and a quadratic profit function. Students were immediately asked to answer a variety of questions about the situation, requiring the use of multiple representations and tools for the analysis of linear and quadratic functions. The CIA content focused on mathematical modeling ideas. For example, students gathered their own data to answer the question of what price should be set for the sale of a special school shirt. They generated demand, cost, revenue, and profit function rules and used those rules to answer the question. The content of CIA focused on families of functions. For example, after they had studied linear, quadratic, exponential, and rational functions, the students engaged in what was known as the "skateboard experiment." They analyzed different possible function rules to describe the speed of a skateboard as a function of the height of a ramp it is transversing. The new content, new foci, and new pedagogy demanded new ways of testing and understanding student understanding.

How Was the Computer-Intensive Algebra *Curriculum Assessed?*

The evaluation of the CIA curriculum necessitated thinking generally about how to evaluate innovative curricula. A useful framework for thinking about curriculum is the notion of the Written, Delivered, and Learned curricula. Our evaluation design included ways to assess and to characterize the nature of what we had written as curriculum, of what the teachers were actually delivering, and of what students were learning.

The ways in which we assessed the written curriculum included two prominent thrusts. First, in formal and informal ways, we traced the development of mathematical concepts through the CIA curriculum. Second, Engelder (Engelder, 1991) analyzed the level of questions in the text and compared it with the level of questions in a popular algebra textbook of the early 60's and one from the late 80's. Doing a task-by-task analysis on material that focused on similar topics, she found that the questions and tasks in the CIA text were at a higher cognitive level than those of the traditional texts.

We also analyzed the delivered curriculum through systematic classroom observation and through extensive naturalistic lab notes and field notes. Careful analysis of whole-class discussion showed that the mathematical discussions in CIA classes included more emphasis on mathematical modeling, problem solving, and a variety of representations. The traditional algebra classes with which we compared the CIA classes focused on symbolic representations in non-applied-settings, with a major emphasis on algorithmic procedures (Heid, Sheets, Matras, and Menasian, 1988). We concluded that, when computing tools are available for the execution of routine procedures and the production of graphical representations of functions, beginning algebra students can (1) engage in more whole-class discussion of mathematical modeling and problem solving; (2) spend more time talking about a greater range of representations; and (3) spend less time talking about routine symbolic manipulation.

Our naturalistic observations over a period of several years (Heid, Sheets, and Matras, 1990) led us to the conclusions that teacher and student roles and responsibilities change naturally in tool-intensive environments. Teachers become facilitators, technical experts, and collaborators while students become fellow experts and individuals who are more responsible for their own learning. These changes in roles and responsibilities are ones that simply did not appear in traditional "chalk-and-talk" mathematics classrooms. At first, teachers found the changes uncomfortable, but after a while they were unable to resist them.

Probably our most intensive efforts in evaluation over the past seven years have centered on finding ways to assess what students had learned. We created and administered technology-intensive paper-and-pencil tests and task-based interviews (Heid and Zbiek, in progress) and found that CIA students outperformed their counterparts on mathematical modeling tasks.

ERIC

Matras found that CIA students performed better on several measures of problem solving (Matras, 1990). Zbiek and Heid (in progress) have conducted several series of intensive task-based interviews with CIA students with promising preliminary results regarding the abilities of the CIA students in the use of strategies and representations, in the understanding of concept of function and in strategies and concepts related to mathematical modeling, and in the understanding of families of functions. Through analysis of these interviews, we are beginning to get better understanding not only of what students can learn in computer-intensive environments but of how they learn.

The Computer-Intensive Mathematics Education Project—The Institute

For the past year at Penn State, we have been concentrating our efforts on the Computer-Intensive Mathematics Education Project (CIME), a research/teacher-enhancement project designed to study ways to empower mathematics teachers in computer-intensive environments (Heid and Blume, 1992). We have concentrated our efforts in three areas: mathematics, mathematics education, and implementation of computer-intensive curricula. The mathematics components have concentrated on developing teachers' understanding of tools and representations, families and functions, and mathematical modeling. The mathematics education component has concentrated on helping teachers better understand their students' understanding. We are helping teachers to create and analyze student performance on tasks that have more than one right answer, on open-ended questions, on projects and explorations, and on student journals related to their learning. These teachers are currently exploring ways to assess their own understanding of their students' understanding through task-based interviews. Throughout this process, the teachers (in 15 different states) are struggling with finding alternative ways to assess student learning.

Implications of Computer-Intensive Algebra and Computer-Intensive Mathematics Education for the Role of Mathematics Faculty from the Scientific Disciplines in the Undergraduate Education of Future Mathematics Teachers

Through our work with CIA and CIME, we are growing in our understanding of teaching and learning mathematics in computer-intensive environments. Our results have implications for content, pedagogy, and use of technology in college classrooms that are preparing future mathematics teachers. Those classrooms need to model some of the alternative assessment strategies explored through the CIA and CIME projects. Future teachers can benefit from being themselves assessed in alternative ways: through problem-solving journals, open-ended problems, group projects, and task-based interviews. College mathematics teachers can expand on the methods used in the CIA/CIME projects and incorporate alternative assessment techniques in the classes they teach to future teachers. Such use of alternative assessment is likely to have multiple benefits. Through alternative assessment college mathematics teachers can better understand their own students' understanding. They can use this information to improve their own teaching. And, finally, they can, in the process of improving their own teaching, provide future teachers with models of ways to improve their own understanding of students' understanding.

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Assessing What Students Know, What Students Think They Know, And What They Do

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Introduction

At Clemson University, strategies for grading free response questions on the Advanced Placement Biology Examination are used in large biology lecture courses to assess students' knowledge and their ability to handle data, solve problems, and integrate concepts. These methods can be used to improve students' writing abilities and to prepare preservice teachers to assess student responses.

Clemson University's Biology Program also employs touch screen multimedia kiosks to assess what students think they know about a subject. This information is used to introduce new lecture concepts and to demonstrate to students how misconceptions can often interfere with clear understanding.

Investigative laboratories, a hallmark of Clemson's Biology Program, provide a chance for instructors to assess what students can do as they struggle to gather information, formulate questions, design experiments, and then carry out these experiments and analyze their data.

Part I — Assessing What Students Know

The Advanced Placement (AP) Examination in Biology, consists of a 90-minute free response section (four free response questions). This free response section is evaluated by high school AP Biology teachers and college biology faculty who serve as readers for the Educational Testing Service. In 1992, approximately 41,000 papers, each containing responses to four essay questions, were evaluated by 107 readers. Papers are evaluated using standards that are developed by a group of experienced question leaders and are refined by table leaders and readers assigned to read specific questions. Detailed data on experienced readers, including information on number of papers read, conformity, grading lenience, and grading dispersion on previous examinations, are used to assign readers to questions. Answers are

scored on the basis of 10 points. Points are given for correct information or responses only. No points are deducted for incorrect information.

This type of performance assessment allows for:

(1) *Large numbers of free response questions to be graded fairly and accurately.* During the reading, detailed information on reader means, question means, variability, and relative mean essay scores (essays compared with objective score) is processed twice daily. This allows table leaders and question leaders to work with readers experiencing difficulty in interpreting and applying standards and promotes consistency from morning to afternoon and from day to day throughout the reading. A reader's own consistency is measured by rereading books that were processed earlier in the day or week. The papers are unmarked so that readers are unaware of those papers being used to assess reader consistency.

    This type of assessment can be used for large lecture classes and papers can be graded fairly quickly by a group of readers (including participating faculty or teaching assistants).

(2) *Responses that require problem solving, handing data, and integration of concepts by students.* Questions can provide data and ask for interpretation, require students to design experiments and predict outcomes, report knowledge of structures and processes, apply themes across subject matter, or draw relationships between or among concepts separated by time (old ideas supported by new technologies) or topic (ideas presented in separate parts of textbooks).

(3) *Teaching students to write a coherent, well-organized, free response.* Asking students to develop standards and use them to grade essay examinations of fellow students sharpens the students' own writing abilities. Students can be asked to develop standards with others in a group setting or standards can be prepared as a collaborative activity. When students try to apply standards and make decisions about the quality or correctness of responses, the value of clear, focused, and well organized writing becomes obvious.

(4) ***Assessment of factual knowledge or of thinking, reasoning, and understanding.*** Current trends in AP Biology are focused on concept development and grading of student responses in a more holistic manner. This is consistent with assessing a student's ability to solve problems, to reason, to apply knowledge to new ideas or situations, and to demonstrate his or her ability to think critically and understand broader ideas.

Part II — Assessing What Students Think They Know

The Educational Information Technology Laboratory (EITL) at Clemson University is a multimedia support facility for faculty members in the College of Sciences who are engaged in developing multimedia presentations and applications for teaching biology, chemistry, physics, astronomy, geology, and mathematics. A proprietary license from AT&T supports the development of two software packages: *InteractiVision* PRESENTER and *InteractiVision* AUTHOR. These packages allow faculty familiar with MS DOS to develop presentations by using images from a variety of sources (including flat art, animations, 2 X 2 slides, videotape, and videodisc) and sound (including voice, music, and sound effects) to enhance lecture, provide one-on-one learning experiences, or create interactive problem-solving experiences. This interactive multimedia software runs on a microcomputer with an 80286 (or higher) processor and uses the Targa graphics adapter so that images can be delivered by video projector in large classrooms or by TV in smaller settings. The graphics output of this multimedia system is standard NTSC video so that it can be used to produce videotapes or videodiscs and will support distance learning using video technology.

For assessment purposes, individual student response boxes can be hooked into the system to

allow up to 200 students to interact with the lecturer in an interactive, quizlike setting or an informal "need to know" situation. Data on responses, including gender, race, or age distribution can be immediately projected for review by the audience.

As a modification to this classroom setting, EITL developed a free-standing kiosk, presenting an "ecology quiz." The kiosk was placed in the Student Union. More than 2,500 students interacted with the kiosk in a five-day period. Data collected from this quiz were used to open a discussion on the environment with students in freshman biology classes. Students' own responses could be compared with campus data. This provided students with a reason or a "need to know" more about the environment.

Part III — Assessing What Students Do

Drs. Robert Kosinski and Jean Dickey of Clemson University's Biology Program have been responsible for implementing an investigative laboratory program in a large (1,200 students/semester) nonmajors biology laboratory course. Nonmajors use written materials, videotapes, and computer software to gather information and design and conduct original investigations.

Problems involved in offering such open-ended experiences for large numbers of students include (1) unpredictable equipment and materials needs, (2) low student skill levels, (3) lack of knowledge about how to design investigations, and (4) lack of large numbers of instructors or graduate students trained to conduct and assess student investigations. These problems have been overcome in Clemson's investigative laboratory setting. Investigative laboratories have been running successfully for seven semesters.

Students are introduced to the investigative processes using FISHFARM, a computer program that allows students to determine the correct culturing conditions for a fish and then to raise this fish to make a profit. Students can design experiments without concern for equipment, how long the experiment might take, or the cost involved. Thus, students are free to explore and be at risk in the experimental situation. Students are given background information on aquaculture, scientific data presentation, and report writing. Outcomes are assessed on presentation of data, clear association of data with hypotheses and methods, discussion content, discussion presentation, and conclusions.

After completing FISHFARM, students are introduced to WETLABS. A laboratory discussion on elements of an experiment, designing and performing experiments, and reporting data is presented along with a sample experiment proposal. Students then view videotapes or "methods modules" that introduce laboratory techniques and equipment used to measure a particular event (e.g., change in pH, evolution of O_2). Modules cover topics in two units: physical and chemical nature of cells and cellular metabolism. The modules provide a remedy for lack of student knowledge and skills and also offer suggestions using techniques for which equipment and supplies are readily available. Students work in groups of three. They view the methods modules and then develop a proposal for their experiment, including the experimental design. This is discussed with the laboratory instructor by appointment, outside laboratory time. The proposal is then presented orally to the class for further critique and revision. A supplies and equipment list is presented to the instructor and the experiment is carried out during the next laboratory period. Oral and written reports are presented during the following laboratory period. Written reports are prepared following the format and suggestions in a special writing guide.

After completing one WETLABS investigation in each of two units, students design and perform a third experiment to extend one of their earlier investigations.

Evaluation of the effectiveness of the program is mixed. Even though investigative laboratories eliminate lecture review, no significant difference was seen in performance on lecture examinations. However, even though investigative laboratori mphasize process skills, there

was also no significant difference between traditional and investigative students in scores on process skills tests, on a test of the nature of science, or on student writing samples. The investigative approach is used in only two-thirds of a semester, but is being extended to the entire course with the expectation that improvements in process skills will be apparent with increased student exposure to the investigative laboratory environment.

This approach has also been extended to a new series of science courses for elementary and early childhood majors in education. This course uses the learning cycle to explore, discuss, reason, and apply knowledge gained from class work and experimentation. Students apprentice with teachers in the schools for real-world experience that provides a positive attitude toward science and children.

Basic Concept Inventories

David Hestenes, Arizona State University

Every science has certain *basic concepts* which must be mastered by students in introductory courses before the subject can be fully intelligible. Otherwise, the course is reduced to an incoherent muddle of jargon. Unfortunately, this is the experience of students more often than not, and few instructors are keenly aware of the problem. It is all too easy for students to learn scientific lingo which masks their underlying misconceptions.

To lay the problem bare, so it can be analyzed and addressed, faculty members must devise reliable instruments for systematically assessing student understanding of the basic concepts and identifying their alternative misconceptions. This note describes characteristics of one such instrument, the *Force Concept Inventory* (Hestenes, Wells, and Swackhamer, 1992), which was developed to assess student understanding of basic concepts in mechanics. It is intended as a guide to constructing similar *basic concept inventories* in other sciences as well as other parts of physics. Details are given in the references.

Empirical Results and Instructional Implications

The Force Concept Inventory and its predecessor (Halloun and Hestenes, 1985) have been administered to thousands of physics students at all levels from high school to graduate school. The results have been remarkably consistent as well as surprising and alarming to most physics professors. The data strongly support the following general conclusions.

(1) Most students enter their first physics course with naive beliefs about the physical world, which are inconsistent with nearly all the basic concepts of Newtonian physics. From the perspective of physics, therefore, these naive beliefs are serious misconceptions about the physical world.
(2) Traditional physics instruction, in universities as well as high schools, is generally ineffective in dispelling these misconceptions.
(3) This result is independent of the instructor and his/her mode of instruction. In other words, all modes of traditional instruction are equally ineffective at teaching students the most basic concepts of physics.
(4) Many physics students retain basic misconceptions even into graduate school. It should be no surprise, therefore, that many high school physics teachers also harbor misconceptions.

The educational implications of these facts could not be more serious. Without grasping the most basic concepts, students systematically miscon-

strue most of what they hear and see in a physics course, and they are forced to rely on rote memorization in studying for exams. This goes a long way to explain the frustration, discomfort, boredom, and humiliation that is so common in introductory physics.

Disabusing students of their misconceptions is a difficult pedagogical problem, because their naive beliefs are so firmly rooted in their personal experience and modes of thinking. Simply pointing out their misconceptions to students is no more effective than traditional instruction. Educational research has led to subtler instructional methods which have become increasingly effective in recent years.

Metaphorical Origins of Misconceptions

To deal effectively with misconceptions about science, one should understand their origins in "common sense" thinking. A strong case can be made for the view that the structure of human cognition is fundamentally metaphorical. Indeed, the metaphorical roots of basic misconceptions about mechanics are not difficult to identify. Here are three important examples:

(1) To help students develop the concept of force, textbooks often tell them that "a force is a push or a pull." This has an unanticipated effect. It encourages students to take "human action" as a metaphor for "force," and this generates a whole family of misconceptions about force as the metaphor is elaborated. For example, the metaphor suggests that "only living things exert forces" or, at least, that forces exerted by living things are different than forces exerted by inert objects. This metaphorical concept of force was common among such intellectual giants of the prescientific age as Aristotle.

(2) A different metaphor underlies the common misconception that "a force is needed to sustain motion." It leads to a different concept of force, which was given the name "impetus" in the Middle Ages when the concept was first articulated. The metaphor regards objects as "containers" that must be filled with impetus to make them move. When the impetus, like fuel, is dissipated the motion stops.

(3) For the interaction between a pair of objects, such as two people engaged in a "tug-of-war," the natural metaphor is "war" or "conflict." This entails that "victory belongs to the strongest," so that, contrary to Newton's third law, the victor must exert a force that "overcomes" the "weaker force."

These metaphors come as easily to mind as our "natural language," so effective instruction in physics must lead students to recognize their invalidity.

Assessment of Conceptual Understanding

The dominant, traditional method for assessing student understanding of physics is a problem-solving test. This method has serious weaknesses which are seldom recognized by instructors. True, consistently near perfect scores on typical problem solving tests is strong, though not infallible, evidence that a given student has mastered the basic concepts. However, this is a rarity, and "partial credit" on most problems is the rule. The most common cause of problem solving failure is probably some basic misconception, but this is seldom diagnosed, and failure is often mistakenly attributed to mathematical deficiencies. Typical problem solving tests are poor instruments for identifying basic misconceptions that need to be corrected.

The Force Concept Inventory is much better at detecting misconceptions, because it systematically probes for understanding of each of the basic concepts in Newtonian physics by a forced choice over common sense alternatives, which are powerful distractors for naive students. Of course, the Inventory does not assess all the skills required for problem solving. However, data given in Hestenes and Wells (1992) show that a good performance on the Inventory (better than 60%) is a necessary condition for good problem solving performance in mechanics.

Educational research shows that poor problem solving performance is primarily due to deficiencies in qualitative reasoning. The Inventory assesses only one component of that qualitative reasoning. A more comprehensive assessment requires qualitative test questions designed for that purpose. Physics teachers tend to avoid qualitative questions, in part because student responses are so distressingly poor. This is a symptom of an underlying problem which should be confronted rather than hidden by "quantitative" problem solving testing exclusively.

For a balanced picture of student learning in physics courses, multiple modes of assessment are needed, including direct tests for basic concepts and qualitative reasoning as well as problem solving. The objectives and benefits of the tests must be clear, as testing exerts a powerful influence on the way students address their courses.

Developing a Basic Concept Inventory

Developing the *Force Concept Inventory* was not as easy as one might think from surveying its deceptive simplicity, though the experience should make it easier to develop Basic Concept Inventories for other subjects. A good Inventory requires two major ingredients.

The first is a comprehensive analysis of the basic concepts and a reformulation suitable for the Inventory. The Inventory of basic concepts must be compact, systematic, and comprehensive, so that a reliable profile of student understanding can be obtained without intruding too much on precious class time. A good concept analysis requires a deep understanding of the subject, so it is not something that a graduate student can be expected to do, nor can it be lifted out of a textbook. Most graduate students suffer basic misconceptions, and textbook treatments of basic concepts have a variety of deficiencies. A close study of the Force Concept Inventory (Hestenes, Wells, and Swackhamer, 1992) will reveal that it goes beyond typical textbook analyses in many ways. Though basic concept analysis is difficult, it is intellectually rewarding, and it is a great help in focusing instructional design on the essentials.

The second ingredient of a good inventory is a thorough survey and classification of student common sense alternatives to the basic concepts. This requires systematic interviews of individual students and analysis of responses to open-ended questions. Graduate students can be a big help on these time-consuming tasks, though considerable insight is needed to design good questions.

The final product is a multiple choice test which probes for recognition of basic concepts with powerful distracters enunciating misconceptions which appear so natural to naive students.

Uses for a Basic Concept Inventory

The most important use of the Force Concept Inventory has been to convince university professors as well as high school teachers that there exists a serious misconceptions problem which is not addressed by traditional instruction. On seeing the Inventory for the first time, the typical professor's reaction is that the questions are too elementary to be informative. This reaction turns to consternation when the professor is faced with the (invariably!) poor performance of his/her class on the Inventory. Teachers who want to know more about how their students think are well advised to use the Inventory as a guide for conducting their own interviews.

A second valuable use of the Inventory has been to evaluate instructional effectiveness by applying the Inventory before and after instruction. This has made it possible to verify that some instructional innovations really do deal more effectively with misconceptions. Our large data base enables meaningful comparisons of instruction at all institutions and all grade levels.

The Inventory can be used as a teaching tool, but this is not recommended, because there are better ways to deal with misconceptions, and that would preclude using the Inventory for evaluation. On the other hand, the systematic analysis of misconceptions in the Inventory

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design (Hestenes, Wells, and Swackhamer, 1992) can be a great help in designing instruction to deal with the problem.

Use of the Inventory as a diagnostic test to identify ill-prepared students entering introductory physics is *not recommended.* In fact, the Inventory is a fairly good predictor of success in traditionally taught courses, but that is because the courses are not dealing with misconceptions effectively. For courses which are effective, the Inventory is not a good predictor. However, the Inventory may be quite useful as a diagnostic test for graduate physics students, judging from preliminary results on about 40 students.

Dealing effectively with basic misconceptions, which the Inventory is designed to detect, is only one of the problems of instructional design. But little headway can be made on other problems if this one is not solved.

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Using Assessment to Promote Conceptual Problem Solving in an Introductory Physics Course

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In the next few pages I discuss two assessment activities that I have been using for two years in a large introductory physics course for science and engineering majors. One activity, the writing of qualitative strategies for solving problems, could be better described as a learning activity which also *happens* to be a powerful assessment tool; this activity helps students form concepts and apply them in problem solving contexts. The second assessment activity, selecting the major principle or concept that could be applied to solve a problem, probes how well students are integrating conceptual knowledge and problem solving. I will argue that, compared with traditional assessment activities, these two activities are better able both to promote and to probe the learning of those aspects of physics that physicists deem most important.

As background it should be pointed out at the outset that the design of these activities was guided by an extensive body of cognitive research. Given space limitations, I can only summarize those research findings that motivated the design of the activities and refer the interested reader to various reviews of the learning and problem solving literature (Glaser, 1992; Mestre, in press; Silver and Marshall, 1990). Research indicates that proficient problem solving is guided by conceptual knowledge; expert physicists begin to solve problems by first cuing on the principles or concepts that can be applied to solve them and then considering a procedure for applying them. In contrast, novice physics students focus on finding and manipulating equations to generate answers with little regard as to the principles that undergird the equations they use. Many students become adept at getting correct answers and consequently get good grades in physics courses, yet fall short when asked to display conceptual understanding (Hestenes and Wells, 1992; Hestenes, Wells, and Swackhamer, 1992). Perhaps most disturbing to physics instructors is the well known fact that, without a conceptual foundation, students quick-

ly forget the many equations they memorized during the course, leaving them with little residual meaningful physics knowledge shortly after the course is over.

To temper the tendency to focus on memorizing equations as a means of doing well in an introductory course and to promote the development and application of conceptual knowledge, I asked students to write *strategies* to accompany the solutions to problems they worked out for homework and exams. Students were told that a strategy was a qualitative plan for solving a problem that contained three main components: the identification of the major principle/concept that could be applied to solve the problem, a statement explaining why the principle/concept applied to the problem, and a procedure by which the principle/concept could be applied to arrive at a solution.

The "definition" of strategy was kept deliberately vague since I did not want students to follow some recipe to generate sanitized strategies; I wanted students to think hard about what a strategy was and to grapple with the concepts they were learning in class. This vagueness was a cause of anxiety for students near the beginning of the course as evidenced by their continued request during lecture or office hours that I explain in detail "what I wanted" in terms of a strategy. My answer was that there were many ways to write a good strategy and that I could not provide them with a fail-proof recipe. Instead, I proposed that they use the following litmus test to gauge the quality of their strategy: If their strategy were given to a friend in the same course who was totally "stuck," then their friend should be able to follow the strategy to at least start, if not outright solve, the problem.

Strategies were modeled for students every time I worked out an example in lecture and in the posted answers to the weekly homework problems. Despite initial complaints that they could not do "this strategy stuff" students developed an appreciation of the value of writing strategies; in an informal survey held on the last day of class, students admitted that writing strategies helped them "understand what was going on" in the course and recommended that I continue the practice in future courses that I taught. By the end of the course, approximately one-third of the students could generate excellent strategies, another third could generate reasonably good strategies that showed substantial understanding, and the remaining third generated strategies that displayed major weaknesses in understanding. From an instructional perspective, "not-so-good" strategies were useful in showing me how students were thinking about the concepts that I was teaching in lecture, thereby allowing me to take corrective measures.

Perhaps some examples of student strategies would illustrate their value as both learning and assessment tools. Figure 1 contains a problem from an exam given in the mechanics portion of the course and two strategies, a good one and a not-so-good one.[1] Note how the good strategy contains the three components mentioned earlier, the student identifies the major principle that could be applied to solve the problem (conservation of mechanical energy), states a reason for why it applies (there are no external nonconservative forces acting on the system), and provides a general procedure describing how to apply conservation of mechanical energy. This strategy clearly contains information about the student's understanding of conservation of mechanical energy that could not possibly be extracted from a traditional solution. From a solution, we can only verify that the student used the appropriate equations and that these were manipulated appropriately; however, we have no indication of whether facility with the formulaic aspects of the solution implies conceptual understanding as well. That is, a string of equations and algebraic manipulations contains no information that would allow us to ascertain unambiguously whether or not the student knows when or why a particular concept applies to a given problem. Only by stating that one needs to worry about nonconservative forces before applying conservation of mechanical energy does this student show that she has more than a superficial understanding of the concept.

In the not-so-good strategy the student is simply writing down a shopping list of physics terms, most of which have no bearing on the problem. Students who write this type of strategy have a superficial, almost nonexistent grasp of the physics concepts covered in class.

Not surprisingly, problem solving performance correlates with strategy writing performance—those who write better strategies are the better problem solvers. The next obvious question is whether students who undergo the strategy writing regimen are better problem solvers than students who do not. To explore this question, we compared the performance on the final exam of the strategy-writing students with that of students taking the course from an instructor who did not address strategy writing. We found that the strategy-writing students were no better, no worse at solving traditional test problems than were students from the traditional course. However, important differences in performance emerged between students from these two courses in other measures of expertise. This leads to the second assessment activity.

Since one major observed difference between expert physicists and beginning novices in solving problems is the tendency of experts to focus on identifying the principle that could be applied to solve a problem, we set out to devise an assessment of this skill. We modified a task used in one of our studies of the nature of expertise (Hardiman, Dufresne, and Mestre, 1989) and constructed five multiple-choice questions in which students were asked to read a problem and select the major principle that could be applied to solve it (students were not asked to solve the problems). These five questions were administered to our students and to those from the equivalent non-strategy-writing course in the end-of-semester final exam. Figure 2 contains these five questions, and the performance of both classes. It is clear that students who wrote strategies had a clear advantage in ability to select the major principle that could be applied to solve the problems. In short, strategy writing improves a skill that is well developed among experts.

The value of assessment activities such as the two discussed here from the perspective of educating future cadres of science teachers is clear. Scientists have a hierarchy of the mental tools and skills they use to reason in their domain, with some tools and skills being more valued than others. In the case of physics, what is most valued is understanding those few powerful principles that describe or explain a multitude of physical phenomena and the ability to apply these principles to solve problems across a wide range of contexts. In teaching physics, however, we often fail in designing tasks for students to perform that highlight, and allow them to practice actively, those mental tools and skills we value most. If our goal is to have the students we teach today inculcate genuine physics reasoning in the students they will teach in the future, then we need to shape our instructional and assessment activities so that they are better aligned with this goal.

Notes and References

[1]Although both students supplied "solutions" to accompany each strategy, they are omitted because of space limitations; suffice it to say that the solutions consisted of equations and algebraic manipulations.

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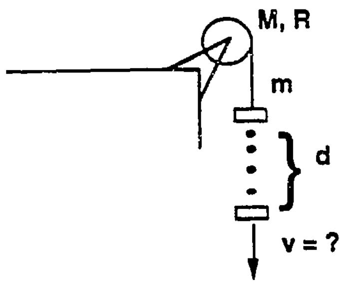
Figure 1. Student Strategies

Problem:

A disk of mass, M = 2 kg, and radius R = 0.4 m, has string wound around it and is free to rotate about an axle through its center. A block of mass, m = 1 kg, is attached to the end of the string, and the system is released from rest with no slack in the string. Without using any equations, provide a strategy in words for finding the speed of the block after it has fallen a distance, d = 0.5 m.



Good Strategy:

I would use conservation of mechanical energy to solve this problem. The mass m has some potential energy while it is hanging there. When the block starts to accelerate downward, the potential energy is transformed into rotational kinetic energy of the disk and kinetic energy of the falling mass. If I equate the initial and final states and use the relationship between v and ω, the speed of m can be found. Mechanical energy is conserved even with the nonconservative Tension force because the Tension force is internal to the system (pulley, mass, rope).

Not-So-Good Strategy:

In trying to find the speed of the block, I would try to find angular momentum, kinetic energy, use gravity.

I would also use rotational kinematics and moment of inertia around the center of mass for the disk.

Figure 2. Principle Identification Assessment

Questions 1–5 refer to the following situation:

Below are five choices, labeled a–e, containing one or more major concepts studied in the course. Questions 1–5 consist of five problems that you do not need to solve. Your job is to decide which major concept(s) needs to be applied to solve each problem in the most efficient manner and make the appropriate selection. Use the same set of five multiple choices for all five questions, and you may use each choice, a–e, more than once.

Multiple Choices:

a) Newton's Second Law
b) Angular Momentum or Conservation of Angular Momentum
c) Linear Momentum or Conservation of Linear Momentum
d) Work–Energy Theorem or Conservation of Mechanical Energy
e) Conservation of Linear Momentum followed by Conservation of Mechanical Energy

Problems:

1. A 2-kg uniform metal bar of length 1 m resting on a frictionless horizontal surface is free to rotate about a pivot at one end. A 5-g bullet traveling perpendicular to the stick hits and embeds itself into the stick 50 cm from the pivot. If the initial speed of the bullet is 300 m/s, what is the angular speed of the stick immediately following the collision?
2. A mass M is connected to a string of length L to form a single pendulum, with the other end of the string attached to the ceiling. The pendulum is released from rest at height $L/2$ from the lowest point of the pendulum's swing. What is the speed of the mass at the lowest point in the swing? Consider the string to be massless.
3. A block of mass m is moving at speed v along a horizontal, frictionless surface. The block undergoes a perfectly inelastic collision with a second block of mass M. The two blocks proceed up a frictionless inclined plane and momentarily come to rest part way up the plane. What maximum distance along the inclined plane do the two blocks travel?
4. A 1-kg stick of length 2 m is placed on a frictionless surface and is free to rotate about a vertical pivot through one end. A 50-g lump of putty is attached 80 cm from the pivot. What is the magnitude of the net force between the stick and the clay when the angular velocity of the system is 3 rad/s?
5. A mass M is connected to a string of length L to form a simple pendulum, with the other end of the string attached to the ceiling. If the mass has speed v at the bottom of the swing, what is the tension in the rope at that point? Consider the string to be massless.

Frequency of Correct Responses

	Problem 1	Problem 2	Problem 3	Problem 4	Problem 5
Strategy-Writing Class (N = 151)	0.78	0.72	0.73	0.40	0.89
Non-Strategy-Writing Class (N = 376)	0.64	0.49	0.58	0.19	0.49

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Experiences for Elementary and Middle School Teachers

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Chair

Panel Members: Michael J. Arcidiacono (The Math Learning Center, Portland, Oregon), Rick Billstein (University of Montana), John R. Carpenter (University of South Carolina), Alan H. Cowley (University of Texas at Austin), Gordon Johnson (Northern Arizona University), Julie Keener (Central Oregon Community College), Susan M. Merritt (Pace University), Jesse Nicholson (Howard University), Crellin Pauling (San Francisco State University), Alvin M. Strauss (Vanderbilt University), Carol L. Stuessy (Texas A&M University), C. Roger Westgate (Johns Hopkins University)

Introduction

Precollege science and mathematics education is currently undergoing intense review and major reform efforts are under way at a national level to provide new visions of what science and mathematics should be taught, how it can and should be taught to all students, and what forms of assessment should be developed and used to measure outcomes. There are implications of the reform efforts for every level of the educational system. The focus of these proceedings is on the implications for the education of mathematics and science teachers and in particular on the role of undergraduate faculty from science disciplines. This particular report focuses its attention on the education of those students interested in teaching at the elementary and middle levels. It is important to acknowledge at the outset that the theme given this group was very large. A discussion about undergraduate programs for teachers of math and science at both elementary and middle levels must take into account differences between elementary teachers who teach all subjects, elementary science and math specialists, middle school math and science generalists, and middle school mathematics and science specialists.

Among the many questions that arose during the deliberations of this group were:

- Is there a common set of introductory experiences that all prospective teachers (all students) should have regardless of future pathways?
- What level of scientific or mathematical understanding should specialists at the ele-

mentary and middle level be expected to achieve?

- When and how should the teaching and learning of science and mathematics be integrated into the course of study of prospective teachers?

The problem we face is very clear. The science and mathematics education of teachers and all non-science and -math students does not provide the fundamental literacy for citizenship, much less than needed for teachers of our children. The reform efforts, the emerging standards, and the new curricula are based on current knowledge and understanding of the nature of science and mathematics, the ways in which children learn science and mathematics, and the teaching strategies that support, guide, and enhance this learning. Teachers must be prepared to teach science and math content that is no longer defined only as facts and figures, but as sets of fundamental understandings, as a way of knowing, as inquiry and problem solving; teaching itself is no longer teacher or text centered, but interactive, supportive, and facilitative; (science and math are learned as they are practiced) assessment is no longer reduced to multiple choice lists and end of chapter problems, but is authentic, continuous, and embedded—as much for guiding instruction as for measuring outcomes.

In order to meet these demands, teachers of mathematics and science must know and understand:

- the nature of the domain—its concepts, context, and applications
- themselves as learners of math and science
- how children learn math and science
- teaching and assessment strategies that are critical to facilitating/guiding the learning of math and science, including interactive discourse, cooperative work, active engagement, relevance, and context

The preparation of teachers in general is currently the focus of much discussion in terms of content, the length of programs, terminal degree, and the extent of collaboration with schools and practitioners. There is also a growing understanding of the need for ongoing professional development throughout teachers' careers. Undergraduate education, and in this case specifically undergraduate science and math education, cannot and should not do all, but the role it plays is crucial. Two assumptions are fundamental to an understanding of its crucial nature. One is that the influence of how teachers were taught on how they ultimately teach is great. And the other is that for many elementary and middle school teachers, the science and math they learn at the undergraduate (often introductory) level is terminal. If these assumptions are accepted, the implications for undergraduate math and science faculty are serious and will require dramatic change in mainstream current practice. The large lecture courses, encyclopedic texts, memorization of terminology, and "cookbook" labs taught by unskilled assistants, all of which characterize much of introductory science and math, only reinforce students' perceptions that math and science are difficult (impossible), boring sets of facts and formulas to be passed on to children. Unless our future teachers are taught the fundamentals of math and science as they are practiced in inquiry and problem solving in relevant, real world, historical, and cultural contexts, they cannot learn to teach students this way.

The four papers presented to the thematic group speak to the need from four particular perspectives and settings. Rick Billstein provides an overview of the work being done at the University of Montana, where prospective teachers of mathematics have a special program in which the learning of content and teaching is integrated. Future teachers learn mathematics and learn how to learn mathematics, which in turn can help students learn how to teach mathematics.

Michael Arcidiacono describes some of the work of the Math Learning Center of the University of Portland, where courses in mathematics have been specially designed to meet the needs

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of preservice and inservice teachers of mathematics in middle school. Both of these programs reflect the belief that there should be special courses in subject matter for teachers.

The working group discussed in detail the article by Caple, Balda, Laughran, and Thomas, *Integrated Science Laboratory Programs—A Holistic Approach,* which appeared in the *Journal of College Science Teaching,* February 1991. The article was presented to the Thematic Group by Gordon Johnson and describes work at Northern Arizona University. Here a traditional introductory lecture/lab course taken by all students includes an interdisciplinary inquiry-based laboratory for prospective science teachers.

Finally, Carol Stuessy describes an innovative teacher preparation course designed around a reflective problem-solving model. She challenges the undergraduate science and math faculty to think about such a model for the teaching of introductory science courses.

While very different in specifics, all four of these programs have certain common elements:

- They provide students with models of how science and mathematics can and should be taught.
- They attempt to engage students as active learners in the study of mathematics and science.
- They emphasize the nature of science and mathematics.
- They are concerned with student learning as well as the transmission of subject matter.
- They also raise a number of questions in addition to the broad ones guiding the theme group discussion:

  — Should courses for teachers be separate?
  — What programmatic differences should there be between courses for elementary school teachers, elementary science and math specialists, and middle school science and math teachers?
  — What should the roles and responsibilities of science and mathematics faculty be, and how should they work together and with their colleagues within education?
  — How can practices and models of good teaching developed for prospective teachers influence the wider undergraduate community? How much integration of math, science, and other domains is important?

Improving K–8 Preservice Mathematics Education in Departments of Mathematics

Rick Billstein, University of Montana

Because mathematics education is in need of improvement at the K–8 level, and because a college degree is required of everyone who teaches at this level, the undergraduate preparation of teachers needs to be examined. Approximately 50% of school teachers leave the profession every seven years. Therefore significant changes can be made by preparing teachers who receive high quality mathematics teaching preparation as described in the National Council of Teachers of Mathematics (NCTM) publication *Professional Standards For Teaching Mathematics* (1991) to fill these positions. The new curriculum materials that are currently being developed throughout the United States will have much more impact if teachers are better prepared both in content and pedagogy to teach these materials. Many institutions of higher education are not responding to this need for improved preservice programs. One reason is that the demand for college mathematics classes, especially at the service level, has increased dramatically. To meet this demand in a time of poor financing, many institutions have responded by increasing class

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sizes or by hiring temporary staff or teaching assistants to teach preservice courses. In other cases, faculty with no background in mathematics education have been reassigned to these courses. These teachers typically do not model the type of teaching described in the NCTM *Teaching Standards*. If people outside mathematics education or teaching assistants are used for teaching preservice courses, they should be prepared through intensive training and be supervised by mathematics educators.

Other problems involving preservice preparation are that colleges do not offer all the NCTM recommended courses for future K–8 teachers and students do not take all the classes. The NCTM *Teaching Standards* calls for a high school background equivalent to two years of algebra and a year of geometry along with nine semester credits of content mathematics for all future K–4 teachers. Teachers of grades 5–8 are expected to have the same high school background plus fifteen semester hours of content mathematics. Most teaching majors take only a subset of this content or fulfill their college requirement by taking courses such as College Algebra or Mathematics for Liberal Arts. These courses are not acceptable for preservice mathematics education. Students typically fear these courses and develop negative attitudes toward mathematics as a result of these courses. Students in these courses are usually exposed to a technology-devoid curriculum that has little to do with teaching K–8 mathematics. The teaching that takes place in these courses usually does not exemplify what is needed for future teachers. Because many preservice students are insecure and are timid about asking questions, classes are needed that are designed for teachers where students share common goals, concerns, and interests, and the instructor is knowledgeable about mathematics education content and pedagogy.

In terms of teacher preparation, the United States is one of a few countries in the world where it is thought that elementary teachers can teach all subjects equally well. Colleges should consider offering mathematics specialists degrees for future teachers of grades 4–8. At the upper grade level, more experience with mathematics is needed and specialists can serve as resource people for teachers of grades K–3. These specialists are different from those being produced by many colleges where students are required to complete an undergraduate major before entering the education program. In almost all cases, these students choose undergraduate subject majors other than mathematics. Consequently, if the education program is not designed with a major component of mathematics content for preservice teachers in the fifth year, schools hire teachers who are not prepared in mathematics.

A goal of preservice mathematics classes is to help future teachers learn how to learn mathematics, which in turn can help students learn how to teach mathematics. This is necessary because students typically retain only a small portion of what they are taught and they need to master concepts and develop critical thinking skills. In preservice courses, students must be exposed to a variety of learning styles and must learn how to learn from the teacher, from each other, and on their own. To receive these experiences, role models are needed. As has been observed, teachers teach as they were taught, not as they were taught to teach. Therefore we need courses that use a variety of teaching techniques: lectures, group work, individual work, peer instruction, and whole class instruction. Students should be presented with mathematically demanding tasks and forced to work through them. Students need an environment where it is acceptable to make mistakes and there is ample room for trial and error. Students should have an opportunity to observe teachers' work through problems and observe the problem- solving process in action. Applications and modeling are topics that should be embedded at all levels. Communication skills must be emphasized. Listening to lectures and taking rote exams will not produce the kind of teachers needed for the future. Preservice students also need exposure to a variety of assessment techniques, including projects, open-ended problems, portfolios, presentations, and paper–pencil tests. Technology must be used, and the role of technology as a

teaching tool must be discussed. It is important to know which tools are appropriate to use and when to use them. Research on mathematics education and discussions of current thinking in mathematics must be a part of the program. This type of preservice preparation can be provided only by teachers trained in mathematics education, current in mathematics education research and philosophy, and who stay in touch with the schools.

Besides some innovative work being done by several commercial companies, there are presently 14 funded full-curriculum projects developing materials for grades K–12. These curriculum projects should all be completed in approximately 5 years and will have a major impact in mathematics education in the United States. These projects will require better educated teachers, because the emphasis in the curricula will be shifted from computation to exploring, conjecturing, and reasoning. Solving nonroutine problems and communicating about and through mathematics will be major components of these new projects. Technology will be an integral component, and most of these new programs will not use a textbook as we now know it but rather modules organized around themes or applications. Students will learn mathematics by doing mathematics. Cooperative learning groups will be built into these projects as well as new assessment techniques. Teaching in these programs will require the role of the teacher to change from that of a lecturer and dispenser of knowledge to that of a facilitator, listener, questioner, and prober. In many cases teachers will become co-investigators with their students in learning and doing mathematics. For the new projects to work, future teachers need to be exposed to similar types of experiences in their teacher preparation courses. This will not happen with most courses in the present college curriculum. Typical college teachers were taught using the lecture method, and this is the method that they feel most comfortable with. If courses for future teachers are taught using this same lecture method and students in turn try to use this method when teaching the new curricula, a mismatch will occur. To prepare future teachers for the new curricula and teaching styles, preservice courses must be redesigned and be taught by appropriate role models.

What can be done by institutions of higher education to better prepare K–8 preservice teachers? The following should be considered:

1. Design courses specifically intended for future mathematics teachers and require that students take these courses.
2. Design a mathematics specialists degree for teachers of grades 4–8.
3. Incorporate national and state mathematics standards for curriculum, assessment, and professional development of teachers into preservice courses.
4. Employ instructional practices and use of technology as described in the NCTM *Professional Standards for Teaching Mathematics* and the MAA *A Call for Change: Recommendations for the Mathematical Preparation of Teachers of Mathematics.*
5. Continually revise and evaluate preservice courses in response to developments in mathematics education and technology.
6. Restore integrity to preservice courses by developing methods of evaluating mathematics competencies of students and their potential as future teachers.
7. Staff preservice courses only with teachers trained in mathematics education who can serve as role models for future teachers.
8. Strive to have all mathematics classes rely less on lecture and involve the students more in the learning process.
9. Reward good teaching and course innovation as well as research at the college level.
10. Educate department chairs and deans of arts and sciences that mathematics education is important: teaching assignments, hirings, and rewards should reflect this importance.
11. Provide technology access such as computer labs and calculators to preservice classes.
12. Provide manipulative materials such as pattern blocks and geoboards to all preservice classes, not just methods classes.

13. Stress applications of mathematics, modeling, and problem solving in the content courses.
14. Have the faculty teaching preservice courses stay involved with schools. College teachers can learn much about teaching from school teachers.
15. Encourage teachers of preservice courses to stay active in professional mathematics education organizations such as NCTM and provide them with travel funds to attend conferences.
16. Have mathematics educators and mathematicians, scientists, and faculty from the schools of education work together to design courses for teachers.
17. Encourage all mathematics faculty to try new materials, teaching techniques, and technology in their classes.
18. Work and cooperate with other institutions of higher education to design and teach preservice courses.

Because teacher education is a "career-long" process, support for teachers should be provided not only during college years but afterwards. Many talented young teachers leave teaching after only a few years. In Montana, in addition to providing the high quality mathematics courses on campus as suggested above, a new program is being developed to plan model schools throughout the state where preservice teachers can communicate with master teachers and observe new curricula in practice. We hope to do this by having preservice teachers communicate with master teachers via a statewide computer network, satellite downlink, and interactive video. The schools in the field will be using innovative curricula such as the NSF-sponsored STEM middle-school curriculum materials currently being developed at the University of Montana. High schools will be using the new Systemic Initiative for Montana Mathematics and Science (SIMMS) curriculum materials. In this way, college teachers as well as preservice teachers can stay involved with schools. As part of their course work, preservice teachers will receive training in telecommunications. The model schools will be used as "living laboratories" for research on effective teaching and preservice teacher supervision.

After future teachers graduate from college, they will be assigned to a mentor teacher who will stay in contact with them either personally or via the modem. The new teacher will also be able to stay in contact with college faculty, other mentor teachers, and other new teachers through the use of the modem. We hope to have this program available for each of the new teachers' first four years and then have these teachers become mentor teachers. New teachers will be provided with a survival kit that contains a modem and a collection of professional journals, books, and other teaching resources. Conferences will be planned for new teachers, the mentor teachers, and college faculty.

All courses for teachers at the Montana colleges and universities will be redesigned by teams made up of mathematics and science educators, mathematicians, scientists, and classroom teachers. Teachers and administrators from the field will serve as advisors in revising the courses. This new plan concerning course revisions, mentor teachers, and telecommunications has not been tried in Montana, but should anticipated funding be received, it will be and then we can see if this new role of academic and education departments can make a difference in terms of teacher training and teacher performance. We think it can!

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The Middle School Mathematics Project: A Program for Preparing Middle School Mathematics Teachers

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Introduction

In 1986, the National Science Foundation awarded Portland State University a five-year grant to develop the Middle School Math Project: A Program For Preparing Middle School Mathematics Teachers. This project grew from previous steps taken by the Department of Mathematical Sciences at Portland State, which had approved a series of courses specifically designed to focus on the mathematics preparation of middle school teachers. The purpose of this paper is to describe these courses and the underlying philosophy of the project.

The goal of the Middle School Math Project is to develop a comprehensive program for preparing middle school teachers in an urban setting. The distinguishing features of the project are:

- It directly relates the content of mathematics courses for pre- and inservice teachers to mathematical content appropriate for middle school students.
- It is geared to the special characteristics of the student population of an urban university and takes advantage of the widespread and varied school resources found in an urban setting.
- It models a philosophy of teaching and learning mathematics that is consistent with current recommendations for effective instruction in middle school classrooms.

Before describing the program in detail, let us look briefly at the rationale on which it is based.

Rationale

One of the major reasons for the emergence of the middle school in the 1960's was the realization that the period of development between childhood and adolescence was more than a phase that youth "passed through." During this period of "preadolescence," middle school students are:

- adjusting to profound and rapid body changes.
- striving for independence and concerned about relationships with others.
- showing increased emphasis about self and environment.
- experiencing a growth in mental ability that enables more abstract thinking.
- possessed with great physical, mental, and emotional capacity to experiment.
- striving for personal values in an active, participatory way.

Early adolescents are persons with specific qualities and characteristics who have certain roles to play, skills to develop, tasks to perform, and things to learn. The degree to which the middle school curriculum addresses the developmental needs of these young people is of major importance. Yet, in the mid-eighties, teacher preparation institutions were responding slowly to these needs. Relatively few programs at any level for middle school teachers were being offered. In addition, there was little (if any) help available to teachers who were most likely to teach in the middle grades, namely those already employed and whose preservice programs had focused on either elementary or secondary school.

Mathematics educators seemed to be among those who had not substantially addressed middle school issues. Very few teacher preparation institutions had mathematics courses specifically for middle school teachers, and certification programs were sparse. Most universities had

secondary mathematics programs as well as elementary and early childhood programs, but none for teachers of early adolescents. Mathematics instruction in the middle school classroom seemed to be characterized by "show and tell" methods that relied heavily on textbooks and allotted little time to group work. This type of instruction seemed consistent with the way most teachers received their conception of mathematics and with their training, but not with what middle school students required.

All of this implied the necessity of offering programs that are accessible to both pre- and inservice teachers (especially in urban areas) in order to significantly impact middle school mathematics teaching. The Middle School Math Project is an example of a program that has worked well in the Portland area and might be helpful for others.

Description of the Project

Portland State University is an urban university serving a metropolitan area with a population of more than 1.3 million. The impetus for a mathematics program for middle school teachers came from many sources: school systems in the area, including the Portland Public School System, were switching to a middle school organization, with the consequence that many elementary teachers became middle school mathematics teachers and wanted more training; some members of the Department of Mathematical Sciences at the University realized that there were no adequate courses for retraining teachers to teach middle school mathematics; and faculty members who had experience offering inservice training to middle school teachers were able to justify the need for special courses to the Department.

Participants in the Middle School Math Project, which evolved from these efforts, complete the courses listed below.

- Computing in Mathematics for Middle School Teachers
- Experimental Probability and Statistics for Middle School Teachers
- Problem Solving for Middle School Teachers
- Geometry for Middle School Teachers
- Arithmetic and Algebraic Structures for Middle School Teachers
- Concepts of Calculus for Middle School Teachers
- Historical Topics in Mathematics for Middle School Teachers
- Teaching and Learning in the Middle School Mathematics Classroom

As the titles indicate, these courses are specifically designed with middle school mathematics teachers in mind. All but the last course are permanent offerings in the Department of Mathematical Sciences and focus on strengthening the mathematical preparation of teachers. The teaching and learning course is offered by the Department of Education. All courses may be taken for either graduate or undergraduate credit.

These courses are offered on a schedule that will accommodate the diverse student population at an urban university (many of the students are inservice elementary or middle school teachers who currently teach, or desire to teach, middle school mathematics, and who have little or no preparation). Classes are scheduled during late afternoons/early evenings and summers on a rotating basis. Staffing requirements are minimal, with one course being offered each quarter and three in the summer.

The Middle School Math Project embodies a philosophy of teaching and learning that recognizes mathematics as an enjoyable human endeavor and invites people to discover the mathematician within them. This philosophy is reflected in the way courses are conducted, where a goal is to create a class environment that models current recommendations for effective middle school teaching. In each of the courses, students are encouraged to construct their own understanding of mathematical concepts by means of the following strategies:

- Inclass problem-solving activities to promote involvement through exploration and experimentation.

- Discussing and listening to how others think about a concept, problem, or idea.
- Small-group work and cooperative learning.
- Becoming aware of one's own mathematical thought processes (and feelings about mathematics) and those of others.
- De-emphasizing formal testing and using other modes of assessment.
- Visual reasoning as well as symbolic deductive modes of thought.
- Supportive class environment.
- Weekly written reports and problem summaries.
- Written communication between instructors and individual students.

Class activities have been developed with this philosophy in mind. These activities are intended to help teachers grow mathematically and model how one can teach preadolescent effectively. The written format of these activities is that used in the Math Learning Center's previous National Science Foundation project, *Math and the Mind's Eye*. The activities, along with other information about the courses in the project, are being compiled into course guides (described below). Here is an example of a starting point for one activity in the problem-solving course (the questions are part of a search for whole numbers that can be expressed as a difference of two squares).

> An el-shape is a square with a square removed from one corner. If 24 square tile are to be arranged into an el-shape, describe the possible el-shapes that could be formed. Describe the el-shapes that can be formed with 36 tile ... with 45 tile.
>
> Investigate further. What numbers (of tile) can be arranged into el-shapes? What conclusions can you draw?

The program carries minimal prerequisites (Introduction to College Math and Foundations of Elementary Mathematics 11), and courses need not be taken in any particular order. With careful planning, it is possible to complete the program in three consecutive summers, or two summers and the intervening year. In fact, teachers typically begin with different courses, so that there is always a mixture of "old" and "new" participants in a class. There is also usually a cross-section of teachers from several grade levels. This diversity of interests and experiences has proven to be very helpful and is something that students have often mentioned with appreciation.

Detailed course guides are being written for each of the mathematics courses in the middle school program. These guides attempt to capture the essence of the courses as they are taught. It is believed that textbook-centered courses are not conducive to the type of mathematical thinking or classroom environment the project wishes to model. Therefore, the course guides consist of a set of materials that contain the philosophy of each course, as well as the mathematical topics, and have a format that is easy for other instructors to use. The guides contain weekly summaries, explorations, class activities, weekly assignments, readings, and transparency masters.

The Middle School Math Project is no longer receiving National Science Foundation funding, but is nonetheless thriving on its own. It has generated considerable interest and respect in the Portland area and has even attracted teachers from as far away as Alaska, Ohio, and Nevada. To date, the average class size has been 20 students, and more than 50 teachers have completed all of the courses. Several people have also incorporated these courses in a Master's program. It is significant to note, too, it has not been necessary to advertise the program.

For further information about the Middle School Math Project, contact L. Ted Nelson, Department of Mathematical Sciences, Portland State University, P.O. Box 751, Portland, OR 97201 (Phone: 503-725-4850).

A Challenge: Employing a Model for Preservice Science Teacher Preparation to the Teaching and Learning of Science by Non-Science Undergraduate Students

Carol L. Stuessy, Texas A&M University

A challenge is presented to teacher educators and educators of non-science-majors to explore the possibilities of using a reflective problem-solving model developed for the preparation of preservice science and mathematics teachers to design innovative problem-solving formats for teaching science to non-science-majors.

Much of the content of this paper is grounded within the context of an innovative teacher preparation course at a large southwestern university designed to integrate methods of teaching elementary mathematics and science (Stuessy, 1993). The course was developed as a prototype for *Teachers As Reflective Problem Solvers* (TARPS), a constructivist model developed by Stuessy and Knight (1993) for the design of courses that prepare preservice elementary teachers to teach mathematics and science.

Basically, the course portrays teaching as a constructivist process (Fosnot, 1989; Pope and DeNicolo, 1991; O'Loughlin, 1992), a viewpoint clearly linked to Kelly's (1965) original work on personal construct psychology. Kelly suggests that persons make sense of the world much as scientists do, by the development of hypotheses, or systems of personal constructs, by which each person tests his or her own explanation of the world. The product is the knowledge constructed by the individual as a result of the problem-solving process within a particular context. Kelly's work has been used consistently in the development of current practices in action learning and action research, both of which rely heavily on the development of effective group problem-solving skills to facilitate the problem-solving processes involved in teaching and learning (Oja and Smulyan, 1989; Brause and Mayher, 1991; Zuber-Skerrit, 1991).

The TARPS model was grounded in two major assertions: (1) Teaching is a problem-solving process (Coldarci, 1969; Zeichner, 1983; Shulman, 1986; Carter, 1989; Zuber-Skerritt, 1991; Goetz, Alexander, and Ash, 1992); and (2) Teachers learn to become effective by reflective practice (Coldarci, 1969; Schon, 1983; Shulman, 1987; Brause and Mayher, 1991; Cole, Messner, Swonigan, and Tillman, 1991). The premise underlying the design of the course was that, in order for teachers to be effective instructional problem solvers, they must constantly test the adequacy of their solution attempts by reflective practice. Reflective practice was defined as a set of learning processes occurring within the teaching-learning enterprise that include "critical interpretation of instruction" (Coldarci, 1969; Cole et al., 1991) and "self examination" (Schon, 1983; Shulman, 1987) and result in a "continuous cycle of growth" (Shulman, 1987; Mayher and Brause, 1991) for teachers who "act out their daily lives as learning individuals " (Brause and Mayher, 1991, p. ix).

The TARPS Model

The Reflective Problem-Solving Format

The concept of "situated cognition" (Greeno, 1991; Winkler, 1992) was applied in the design of the structure of the preservice teacher preparation course. Four practical mathematics and science teaching tasks similar to those confronting elementary school teachers were "situated" as field-based teaching problems. Students were required to *Plan and Prepare, Design, Execute and Evaluate* their preparation and delivery of mathematics and science lessons that they taught to

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elementary school children (Stuessy, 1993). University class time was provided for the preservice teachers to plan, prepare, and design their solution to the problem. To prepare for the solution of the problem, mathematics and science concepts were reviewed, pedagogical strategies were introduced and practiced, and current notions regarding reform in mathematics and science curriculum, instruction, and assessment were discussed. University instruction, laboratory experiences, and assigned readings were directly linked to the problem solution. The problems were designed to become more complex and open-ended as the semester progressed; and the final problem required students to design and execute their own solutions to a problem that they themselves had identified. An essential part of each process was the student's *Reflection* on each of her performances of these processes and on her overall learning during the solution of the problem.

The Assessment

Performance portfolios, assembled by preservice teachers and graded by course instructors, included products and evidence of students' performance in each of the problem-solving categories for each of the four teaching problems (Stuessy and Naizer, 1992). Individual students assembled a performance portfolio for each of the teaching problems. Contents of performance portfolios were organized by problem-solving activity (i.e., planning and preparing, designing, etc.). Although students worked in groups to solve the teaching problems, each student chose her own evidence to represent her performance in the particular problem-solving activity. Students also included written reflections of their performance, which included a reflection on her own learning, including the connections she made with prior knowledge and new knowledge in the classroom teaching experience. An introduction to and justification for the evidence provided for that particular category were also required. Course instructors developed scoring rubrics according to procedures suggested by Randall, Lesser, and O'Doffer (1987) to assess the quality of the reflections and products associated with each category. Instructors graded performance portfolios with class volunteers who expressed an interest in the procedures of scoring by rubrics. Students' progress on each category was monitored throughout the semester, and in instances where high numbers of low scores were noted in a particular category, instructors responded by addressing the category specifically in the introduction to the next problem.

A key characteristic of the TARPS model was cooperation and collaboration among members of the course and with their instructors. Students and instructors together worked toward the successful solution of the teaching problems. Much of the problem solution required students to work in groups to reach consensus and make decisions democratically regarding problem solution. A self-evaluative measure, the *Group Procedural Skills and Abilities Self-Evaluation Questionnaire* (GPSASEQ), was developed to monitor and assess students' self-perceptions regarding their abilities to solve problems successfully in groups (Stuessy, Naizer, Bryant, and Tucker, 1993). The instrument consisted of 21 Likert-type questions that requested students to assess their abilities in the five problem-solving activities associated with the solution of the teaching problems: *Planning and Preparing, Designing, Executing, Assessing, and Reflecting*. Students were administered the GPSASEQ at the beginning and end of the semester of the methods course. In students' *Final Reflections* that occurred at the end of the semester, students included an analysis of the changes that had occurred over the semester in their perceptions of their group problem-solving abilities.

Action Research

The instructors of the course developed the *Teachers As Reflective Problem Solvers* (TARPS) model to simulate the real world of the elementary classroom. Similar to the action research model commonly used for inservice teacher

development, the TARPS model led to a course design where groups of preservice teachers solved problems that were similar to those they would experience as classroom teachers. In the process of designing and executing their "problem solutions," students used data that they collected from their peers and elementary students to assess their effectiveness as teachers. Additionally, students were encouraged to construct their own knowledge by the requirement that they engage in reflective practice. The final problem of the semester required students to identify and solve a problem that they themselves had identified, a problem most typical of the open-ended problems that practicing teachers encounter daily. Hopefully, the group problem-solving experience in the class was valued and that students, as they enter their teaching experiences, will seek others to solve similar problems by action research methods.

Research activities by the instructors associated with the development of the TARPS model and its prototype lend support to the model of teachers as reflective problem solvers. The course provided an action research context for the university instructors, who engaged in problem identification and solution during the development and refinement of the course. Early development of the performance portfolio, which combined elements of both performance assessment (Baron, 1990) and portfolio assessment (Collins, 1991), was justified (Stuessy and Naizer, 1992), and issues of validity and reliability regarding the performance portfolio eventually were resolved (Naizer, 1993). Additionally, action research resulted in the development of a traditional Likert-type instrument, which was validated later to monitor students' perceptions regarding their own problem-solving skills and abilities in groups (Stuessy, Naizer, Bryant, and Tucker, 1993). The use of that instrument led to its incorporation as an integral part of the students' *Final Reflections* on their experiences in the course. In the course of developing the instrument, students' scores on the self-reflection measure were compared to instructors' performance-portfolio ratings and to an analysis of final reflections that were analyzed by the inductive-analytic procedures outlined by Lincoln and Guba (1985). Clusters of reflective statements were categorized to represent generalities in students' reflections to indicate levels of complexity, description, and critical self-assessment and -examination. Conclusions regarding the roles and interactions of reflection and problem-solving processes were examined by Stuessy and Knight (1993) to reveal patterns of change in preservice teachers' reflections as well as interactions between problem-solving performance categories and reflection.

The results of the action research studies associated with the development of the course emphasized the power of the performance portfolio as a research tool as well as a non-intrusive, authentic assessment that guided and served instructional practice. In-depth examination of the performance portfolio revealed differences in preservice teachers' abilities to plan, execute, deliver, and reflect on their teaching that are corroborated by other research in teacher education (e.g., Housner and Griffey, 1985; Berliner, 1986; Carter, 1989; Cole et al., 1991). The research activities of both preservice teachers and university instructors provided a provocative concept for preservice preparation that is still being explored: that the methods classroom can provide a context for all to engage in the teaching–learning enterprise as instructional problem solvers and involve them in the process of testing the adequacy of their solution attempts by reflective practice.

The Challenge

Instructors and students who were involved in the development of the "reflective problem-solving" model were committed to high levels of inquiry regarding all aspects of the course, including the design and execution of the field-based problems, the choice of preparatory learning experiences, and the structure of the assessments. The overall objective was to optimize the

preservice teachers' learning of useful, practical pedagogical knowledge associated with elementary school mathematics and science. What if the overall objective of a science course for non-science-majors were to optimize the learning of useful, practical science knowledge associated with solving complex, open-ended "learning problems"?

Perhaps such a "reflective problem-solving" model would also be helpful in preparing preservice elementary teachers to be *learners*, as well as teachers, of science. Maybe the constructivist perspective of Kelly would be useful in designing science courses for nonmajors. Perhaps the concept of "situated cognition" (Greeno, 1991; Winkler, 1992), found to be useful in designing practical teaching problems for preservice teachers, might also work to optimize the learning conditions for nonscience students learning science. What if science learning were packaged into some sort of "situated learning problem" that required students to plan, prepare, design, execute, and evaluate their own solutions to a practical problem that incorporated the learning of science into its solution? What if science knowledge were assumed to be an essential component of preparation for the problem solution, rather than the product of the problem itself? What would a science classroom look like, if learning were viewed as a social interaction, where the processes and products of learning were experienced as collaborative and cooperative rather than individualized and competitive? And what if reflection were viewed as a personal, individualized product of an integrative, synthetic, constructivist process: the product of an individual's "making sense" of all aspects of the problem, including the development of new understandings about science within situated, real-world contexts? And what if a new assessment strategy, such as the performance portfolio, were employed to assist, monitor, and guide not only the learning of students but the teaching of the instructor? And finally, what if the teaching and learning environment for non-science-majors also provided a safe research environment for all to learn more about the processes of teaching and learning science?

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Discussion Summary for the Thematic Panel on Experiences for Elementary and Middle School Teachers

Karen Worth, Education Development Corporation, Newton, Massachusetts

Wide-ranging discussions followed the four presentations to the group. While touching on many aspects of the theme, the group's major focus was in five areas. Brief descriptions of these follow.

Acquisition of the Subject Matter Base

The group agreed that the acquisition of the subject matter base for both prospective elementary and middle school teachers should be through active, hands-on inquiry-based learning. Powers of observation should be honed, collaborative learning encouraged, and group problem solving should be employed in the instructional process. The principle of less content studied at greater depth was endorsed, with a strong feeling that the goal should be an understanding of principles rather than memorization of the mass of facts. A cross-disciplinary approach to the instruction was supported particularly for the prospective elementary teachers.

The group also agreed that faculty at the university level need to involve inservice teachers in the design and planning of curricula and courses that serve preservice teachers.

Separate Courses for Preservice Teachers

There seemed to be a consensus among the group members that in the best of all possible worlds there should not be separate introductory science courses for preservice teachers in the science disciplines. If the courses were designed as described above, they would at the same time serve preservice teachers, the general student, and science majors. The group was persuaded by the arguments of Rick Billstein that separate courses for preservice teachers are desirable in mathematics.

Differences in the Preparation of Elementary Teachers and the Preparation of Middle School Teachers

The consensus of the group was that middle school preservice teachers should have a more intensive foundation in science and mathematics than elementary teachers. In addition, the group endorsed the concept of science specialists and mathematics specialists at the middle school level.

Strategies for Making Changes at the Colleges and Universities

It was generally agreed among the group members that there is considerable room for improvement in the teaching of science and math at the higher education level, and that it is incumbent upon faculty in these disciplines to effect changes in approach if change in the teaching of science at the K–12 levels is desired. Strategies proposed included:

- institutional commitment to mathematics and science education K–16 and support for necessary reform for undergraduate programs
- revision of the faculty reward structure to reflect a valuing of teaching excellence and innovative curriculum design, based on objective measures of specified goals and outcomes
- the development of model courses and programs that integrate curriculum, instruction, and assessment and that are accompanied by a strong faculty development program
- the use of interdisciplinary labs in conjunction with regular lecture courses, in lieu of the normal lab section

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- greater involvement of professional organizations in support of science teaching

The group expressed a strong need for faculty in undergraduate mathematics and science departments to work together and with faculty in education departments to develop and promote a strong research and development agenda for science education. A strong research base for teaching (curriculum, instruction, and assessment) and learning strategies is essential, with publication of the results in refereed journals. This research should be encouraged, funded, and rewarded in the same way that research in the basic disciplines is encouraged and rewarded in colleges and universities.

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Experiences for Secondary School Teachers

Henry Heikkinen, University of Northern Colorado, Chair

Panel Members: Robert Beck Clark (Texas A&M University), Daniel Fallon (Texas A&M University), William Jaco (American Mathematical Society), Glenda Lappan (Michigan State University), M. Patricia Morse (Northeastern University), David Moursund (University of Oregon), Peter V. O'Neil (The University of Alabama at Birmingham), Saundra Herndon Oyewole (Trinity College, Washington, D.C.), William Sayle II (Georgia Institute of Technology), Kenneth L. Verosub (University of California, Davis), Karan Watson (Texas A&M University), Paul Williams (University of Wisconsin—Madison), Beverly Park Woolf (University of Massachusetts), Vera Zdravkovich (Prince George's Community College)

Introduction

Vera Zdravkovich, Prince George's Community College

I hear and I forget
I see and I remember
I do and I understand
—Confucius (200 BC)

We remember
20% of what we hear
40% of what we see
70% of what we do

The major issues that emerged from the panel on Experiences for Secondary School Teachers were

- Content
- Framework
- Role of technology
- Role of research in undergraduate curriculum

The content of the undergraduate science and mathematics classes for teachers should be supportive of the content of the precollege curriculum. Consequently, the discipline content parameters in terms of what students should know at the end of the 12th grade must be established. Closely related to this is the extent

and type of knowledge that will empower teachers to choose judiciously what they will teach, at what pace, and in what manner. They must be equipped with the know-how to judge the level of student thinking in order to optimize the classroom experience. To make topic selections, design or mold the curriculum, and develop new and interesting laboratory or hands-on experiences, teachers must possess thorough understanding and knowledge of the discipline and be guided by it. Discipline pedagogy involves meaningful understanding of content evidenced by the ability to use many and different metaphors. The undergraduate faculty can help construct the content knowledge of students to become "doers of the discipline" rather than transmitters of information.

The framework necessary for effective classroom teaching includes interactive classroom discourse, a positive classroom environment, and continual analysis of the process. The discourse is described by the *Professional Standards for Teaching Mathematics* (PSTM) as "the ways of representing, thinking, talking, agreeing, and disagreeing" (Reston, VA: National Council of Teachers of Mathematics, 1991, p. 36) as a group of students and a teacher strive to make sense of the discipline. Future teachers need to be exposed to, and engage in, discourse in their own undergraduate classes in order to be able to use it once they assume their professional roles. By modeling for future teachers the techniques for engaging students in classroom discourse, we will create a community of scholars.

Preservice teachers need to experience scientific learning in an environment that values thinking, explanations or arguments, and decisions based on evidence. What teachers and all students learn is closely connected to how they learn it and to the environment in which they learn it. A teacher's repertoire of classroom skills is based on the total experience of schooling. As part of their undergraduate education, teachers need to experience a classroom environment in which they will feel empowered to think and analyze, and one that will build their self-confidence as learners of science.

Future teachers need to learn how to assess students' progress for the purpose of making effective instructional decisions and to provide the feedback needed to assess goal attainment. They need to learn how to analyze their classrooms in the future in terms of the extent of classroom discourse, the quality of the classroom environment, and the content tasks they assign. The only way future teachers will learn how to do it is if it is modeled in their own undergraduate classrooms.

Technology can enhance students' depth of understanding and subject comprehension. Successful integration of instructional science and computer science can lead to the development of a powerful teaching system. If achieved, this integration would move beyond the ability of either separate discipline to improve student learning. One of the barriers to successful integration is the gap between the two disciplines in terms of goals, motivations, and literature. Computer scientists could clarify the process of building knowledge-based tutors so that instructional designers and others might collaborate in their design. Informational technology and computers should be an integral part of a science classroom and laboratory in particular.

The panel members appreciated the possible impact and enhancement technology presents for learning science and mathematics. However, the prevailing concern was relative to the resources necessary to bring the technology to the classroom in an effective way, and a balance that must be established between the role of the teacher and that of the technology.

Research can play an instrumental role in the learning of science. Research experiences need not wait until the senior year at the university or until graduate school. They can be incorporated successfully in science courses at a very early stage, even in freshman year. The advantages of effective incorporation of research and research methods into science classes are many:

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- It promotes active student involvement,
- It promotes an investigative approach thus modeling how science works,
- It provokes thinking and classroom discourse,
- It creates a positive classroom environment, and
- It can involve other sciences and provide the basis for an interdisciplinary approach.

The research should always be supported by in-depth content, with the faculty reinforcing students throughout the process.

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Training Teachers or Educating Professionals? What Are the Issues and How Are They Being Resolved?

Glenda Lappan
Sarah Theule-Lubienski
Michigan State University

Current trends in teacher education cannot be separated from the current visions of student learning. As Brown, Cooney, and Jones (1990, p. 650) state, "It makes little sense to interpret either students' goals or teachers' goals in isolation one from the other." Hence, we will begin by exploring today's vision for mathematics students and its implications for teaching and teacher education.

Vision of Student Learning of Mathematics

What society needs from mathematics education for students is changing dramatically. In order to address these changing needs, the National Council of Teachers of Mathematics (1989) created the *Curriculum and Evaluation Standards for School Mathematics* (CESSM). This vision of reform promotes several inter-related components, including: (1) students actively "doing mathematics", (2) mathematics as thinking and sense-making, (3) powerful, but changing, mathematical content, and (4) a belief that all students can learn and appreciate mathematics. The implications of this vision of mathematics and mathematics learning for teacher education and professional development are major. We need to begin at ground level and build teacher education programs that can educate and support teachers in changing their minds and their practice to support more powerful mathematics and mathematical thinking for students.

A Framework for Examining Teaching

There are many persistent obstacles to making change in the teaching and learning of mathematics. In order to examine pre-service teacher education programs and professional development programs for experienced teachers for the likelihood that they can help teachers make change, we need to build a framework of what teachers need to know and be able to do. Teaching is a very complex endeavor, not reducible to recipes or algorithms. Good teaching may look very different in different classrooms. In order to get beyond the

surface features, one has to examine aspects of the teachers' decision making, judgments about the classroom, and about the students' learning.

The writers of the Professional Standards for Teaching Mathematics (PSTM) identified four aspects of teaching that were judged to be so central to good teaching that they could be used to craft a framework, in the form of a set of standards, about what teachers need to know and be able to do. These four aspects of decision making are choosing worthwhile mathematical tasks, orchestrating classroom discourse, creating an environment for learning, and analyzing teaching and learning. (NCTM, 1991)

Worthwhile Mathematical Tasks

There is no other decision that teachers make that has a greater impact on students' opportunity to learn and on their perceptions about what mathematics is than the selection or creation of the tasks with which the teacher engages the students in studying mathematics. Here the teacher is the architect, the designer of the curriculum.

To make selections or craft tasks that give students these deeper, more relevant opportunities, teacher must be guided by the mathematical content of the task. Problems should not be chosen merely because they are "fun", or use a manipulative that is available in the classroom. There must be the potential for students to engage in sound and significant mathematics as a part of accomplishing the task.

A second consideration of a teacher in selecting or crafting tasks is that he or she teaches particular students. What the students already know and can do, what their mathematical needs are and the level of challenge they seem ready to accept are all fundamental issues for a teacher. For teachers to be effective at making such judgments they need to know the best results that we have from research and practice about students of the age in question as well as to have particular insight into their own students' mathematical progress and ways of making sense of mathematics.

We must build responses to the following questions in our teacher education programs::

> *What knowledge does a teacher need in order to be able to judge what her students know, to be able to recognize the difficulties that they are experiencing, to anticipate what will be difficult, to anticipate what will be*

more apt to push students forward in their thinking and their knowledge and skill in doing mathematics?

Classroom Discourse

The PSTM describes discourse as " the ways of representing, thinking, talking, agreeing, and disagreeing" (1991, p.36) as a group of students and a teacher strive to make sense of mathematics. Discourse includes the ways that ideas are represented, exchanged, and modified into more powerful and useful ideas. Teachers have a critical role to play in establishing the norms of discourse in the classroom and orchestrating discourse on a daily basis. It is through the interactions in the classroom that students learn what mathematical activities are acceptable, which need to be explained or justified, and what explanations or justifications are acceptable.

The implications of new forms of discourse in the classroom are very great for teacher education. Many teachers and intending teachers have never experienced learning mathematics in situations where what is valued is the quality of the thinking, the quality of the explanation or argument, and the quality of the decisions made based on the evidence. Additionally, many teachers and intending teachers have little experience using tools-- intellectual as well as physical tools such as calculators and computers-- as ways of modeling, exploring, or representing ideas.

As Teacher Educators the question we must ask ourselves is

How do teachers learn to conduct discourse in such powerful ways?

Classroom Environment

What students learn is fundamentally connected to how they learn it. The environment in which students learn affects their view of what mathematics is, how one learns it, and perhaps of more importance, their view of themselves as a learner of mathematics. Environment means more than the physical surroundings. It includes the messages that students are given about what is expected of them. What is their work to be? What counts in the classroom? Is it speed? Neatness? Being quiet? Completing tasks? Or is it taking responsibility for listening to and helping others? Asking questions of themselves and of

their classmates? Seeking evidence? Being curious? Working independently? Sharing ideas and strategies?

Environment encompasses considerations of tasks and discourse and the emotional climate of the classroom. Is the environment of the classroom conducive to taking intellectual risks? Does every student feel valued? Does every student feel that their ideas will be respected even if they turn out to be incorrect? Does every student expect to make conjectures or argue points or question each other as they build their mathematical understanding? These questions raise further questions about our teacher education programs:

> *How can teacher education programs and professional development programs help teachers develop learning environments in which students feel empowered to make sense of mathematics and in which they feel confident in themselves as learning of mathematics?*

Even if teachers, both pre- and in-service, have experienced such an environment for learning mathematics, it is unlikely that such experience makes explicit the decisions that a teacher makes and the ways that a teacher works to build such an environment. The teacher as analyzer, as researcher, is visible to the students only through tests and other means of evaluation. Perhaps this final aspect of decision making is the most elusive of all since here there is little outward evidence of the teacher's analysis.

Analysis

How well is the system that the teacher has created working? Are the tasks engaging the students? Are they effective in helping students learn mathematics? Do they stimulate the richness of discussion that students need to develop mathematical power? Is the classroom discourse fostering learner independence? Curiosity? Mathematical thinking? Confidence? Disposition to do mathematics? Is the classroom environment encouraging the kind of engagement that reaches every student and supports their mathematical development? These are the kinds of questions that reflective teachers regularly ask themselves. The PSTM refers to these aspects of teacher reflection as analysis.

Analysis also includes the regular assessment of student progress for the purpose of making instructional decisions. Assessing student performance on skill level items is not

sufficient. The teacher needs to examine all aspects of the mathematical development of students including how the tasks, discourse, and environment are working to build mathematical power for all students.

In the same way that we argue for an environment for students in which they can explore mathematics we have to consider that preservice teachers do not learn pedagogical reasoning by being told. The environments that we build in which to educate teachers must help preservice teachers construct their own professional knowledge. Teaching is a creative act in much the same way that problem solving is a creative act. It may help to know some heuristics for attacking problems, but a list of heuristics will never make us problem solvers. It may help preservice teachers to have some heuristics with which to consider teaching situations and problems, but such a set of "how- to's" will not make one a professional teacher capable of making the kinds of decisions that are envisioned in the PSTM and the CESSM.

How is a teacher to learn how to make such decisions and to engage in such analysis? What experiences in pre-service programs or professional development activities with experienced teachers are effective at developing such professionalism in teachers?

We now turn to an examination of the kinds of knowledge that we must consider in our professional development programs for teachers if we are to develop answers to the questions raised on what teachers need to know and be able to do and where they will learn it.

What do Teachers Need to Know and Believe?

Teachers need knowledge of at least three kinds to have a chance to be effective in choosing worthwhile tasks, orchestrating discourse, creating an environment for learning, and analyzing their teaching and student learning: knowledge of mathematics, knowledge of students, and knowledge of the pedagogy of mathematics. These domains of knowledge can be represented in a Venn diagram as shown:

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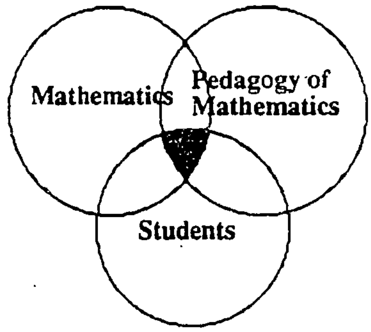

However, the Venn diagram makes clear one of the problems. Teachers work in the intersection of these domains of knowledge. It is the interplay of the various considerations that leads to defensible pedagogical reasoning on the part of teachers. Yet in teacher education programs we typically engage students in each of these domains of knowledge in isolation from each other. The integration of that knowledge in ways that helps a teacher reason about their classrooms and their students is often left to the student teaching experience. The evidence suggests that this is not an effective means of helping teachers see the connections among the various domains of knowledge that they possess. (Feiman-Nemser, 1983)

In the next sections of this paper we will examine issues and promising research in areas of teacher learning that reflect the three areas or domains of knowledge diagrammed above.

Knowledge and Beliefs About Mathematics

The new vision for student learning has great implications for the knowledge of mathematics needed by teachers Encouraging students to explore mathematics sometimes leads to unexpected mathematical questions and situations, and teachers need mathematical knowledge in order to guide students in their explorations.

McDiarmed, Ball, and Anderson (1989, pp. 13-14) emphasize the importance of teachers' mathematical knowledge. After reviewing current research in this area they concluded:

> Recent research highlights the critical influence of teachers' subject matter understanding on their pedagogical orientations and decisions... Teachers' capacity to pose questions, select tasks, evaluate their pupils' understanding, and make curricular choices all depend on how they themselves understand the subject matter.

Lampert (1988, pp. 163-164) argues that teachers need to know where the mathematics teaching and learning process is headed, "not in the linear sense of one topic following another, but in the global sense of a network of big ideas and the relationships among those ideas and between ideas, and facts, and procedures." A study by Steinberg, Haymore, & Marks, (1985) supports her assertions. They found that well-developed mathematical knowledge correlated with having a more conceptual teaching approach, while a low level of mathematical knowledge correlated with a more rule-based approach. Additionally, Even (1991) found that teachers with limited conceptions of functions taught in a way that emphasized rules without understanding.

McDiarmid, et. al. (1989, p. 7) also state, "Beyond representing the *substance* of a subject, teachers also represent its *nature*." In order for teachers to help students obtain more authentic and productive notions about mathematics, teachers themselves need to believe that mathematics is more than just memorizing rules. Yet, U.S. teachers tend to give inconsistent messages about the goals of mathematics (i.e. neatness, correct answers, rules and procedures). (Stigler and Perry, 1988))

Perhaps these mixed messages are indicative of current questions being raised about goals of mathematics education and the relationship between the discipline of mathematics and mathematics education. Should reasoning, thinking, and problem solving be the primary focus of mathematics education? Or should mathematical concepts, definitions, and theorems be given primary emphasis? To what extent should the classroom community's norms be similar to the norms in the community of mathematicians regarding issues such as evidence and proof?

Despite questions such as these being raised about the relationship between the discipline of mathematics and school mathematics, there does seem to be a great deal of agreement about the importance of teachers' mathematical knowledge. Instead of avoiding these issues with teachers, it might help teachers reconsider their rule-based notions of mathematics to realize that mathematics and mathematics education are both developing fields, in which there are unanswered questions and debate.

It seems clear that it is not just the quantity of mathematics that is at issue. Teachers need to learn mathematics in deeper, more connected ways. In order to develop this depth of mathematical understanding and be able to use their mathematical knowledge effectively in classroom, the current way in which mathematics is taught to teachers must be changed.

Not only do mathematics teacher educators need to model good teaching, they must also give explicit attention to the relationship between teachers' mathematical knowledge and teachers' knowledge of mathematical pedagogy and students.

Knowledge and Beliefs About the Pedagogy of Mathematics

The *Professional Standards for Teaching Mathematics* takes the stand that what students learn is fundamentally connected to how they learn it. "Consequently, the goal of developing students' mathematical power requires careful attention to pedagogy as well as curriculum." (NCTM, 1991, p. 21) Couple this stand with Thom's (1972) suggestion that mathematical pedagogy reflects one's philosophy of mathematics and Hersh's (1986, p. 13) statement "One's conception of what mathematics is affects one's conception of how it should be presented." and this sends a powerful message about what is important in our teacher education programs. What philosophy of mathematics do our students see in our programs? Is it coherent? Does it pervade all aspects of the education of teachers from the content classes in mathematics to how we work with students in the fields? Do we consciously try to make explicit matters having to do with what mathematics is? Do we engage students in activities that cause them to consciously reflect on their deep seated beliefs about mathematics and what it means to know and to teach mathematics?

In recent years research on teachers' beliefs and the interaction between beliefs and practice have received increasing attention. Thompson (1984) investigated high school teachers' beliefs and their classroom teaching and found evidence that teachers' beliefs, views, and preferences about mathematics influence what they do in the classroom. Others who have studied teacher beliefs and the impact on teaching and learning are given in the references for this paper. (Shaw, 1989; Cooney, 1985; Brown, 1985; Dougherty, 1990; Peterson, Fennema, Carpenter, and Loef, 1989; Schram, Wilcox, Lappan, Lanier, 1989; Nespor, 1987; Ernest, 1988) We know from research that the deeply held beliefs of preservice teachers about what can and should happen in school, about what is possible and what is desirable, and about the nature of understanding (Stigler and Perry, 1988) are particularly difficult barriers to change. But we cannot improve teaching unless we confront what teachers bring to teaching and more specifically to teacher education.

In 1988 a group at Michigan State University began a study of preservice teachers as a part of the National Center for Research in Teacher Education. The study was based on an intervention designed to help us better understand what it takes to help preservice teachers

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confront their beliefs about what mathematics is, what it means to know mathematics and what it means to teach mathematics. We designed three courses in mathematics, two methods courses, one before and one after student teaching, and seminars during student teaching. We have written about our work in several papers in the list of references (Schram, Wilcox, Lappan, and Lanier, 1988, 1989; Schram and Wilcox, 1988: Wilcox, Schram, Lappan, and Lanier, 1991; Wilcox, Lanier, Schram, Lappan, 1992, Schram, 1992; Lappan and Even, 1989). Here we summarize what we think we know as a result of this ongoing study.

The 24 preservice teachers entered the first mathematics course with a traditional view of mathematics as a well-ordered sequence of rules and procedures mostly focusing on number and number operations. They did not expect mathematics to make sense, but they did expect themselves to be able to remember or the teacher to give a rule after which the solution would be swiftly found. They perceived the role of the teacher to be explaining how to do the problems and telling the students when they were correct. We had a year with these students in which to create a new vision of what mathematics learning and teaching--from the perspective of the mathematics classroom--could be. We were able to change in very powerful ways how the students perceived of themselves as learners of mathematics. By the end of the intervention, the students valued the kind of environment we had created and the goals of problem solving and deep understanding that had driven our work. However, they valued this as an environment for **themselves as learners, but nearly half of the students still held to their more traditional beliefs about what mathematics was important for elementary children and how one should teach that mathematics to children.**

We have continued to follow a subset of these students through their first three years of teaching (Wilcox, et al, 1992). Our analysis of the data suggests that the choices the teachers make in their teaching of mathematics are influenced by the interaction of their views about knowledge, and pedagogy with the degree to which they perceived the context of the school in which they teach --with its policies and established curriculum-- as a constraint. We have observed the complexities that new teachers face in attempting to create environments for learning mathematics in which children engage in personal and group sense making. We have observed the isolation new teachers feel. We have concluded that disciplinary knowledge and a disposition to engage in mathematical inquiry or sense making can be developed in an intervention such as ours. However, this is not enough to overcome the deeply held beliefs about how young children should learn

mathematics and what is important for them to know. Additional work must be done to create environments in which these deeply held beliefs are challenged, examined, and reconstructed. This cannot, in our opinion, be done solely in the preservice phase of teacher education. In fact, some professional development programs are based on the tenet that teachers need to change their teaching and see that a new approach "works" in their own classrooms before their beliefs change. (Owen, Johnson, Clarke, Lovitt, and Morony, 1988; Lockwood, 1991) Hence, working models of support systems for novice teachers need to be built.

We turn to the third area of knowledge needed by teachers.

Knowledge and Beliefs About Students

Most teacher education and professional development programs try to help teachers learn about children. However, it is where this knowledge of children and mathematics meet that is of critical importance to us as mathematics educators. The site for this meeting in many teacher education programs is in the student teaching experience. Yet, many of us have experienced the disappointment of students returning from student teaching experiences angry at the university faculty because the world of school was not what their teacher education program espoused. The hard work of moving pre-service teachers to reconsider their beliefs and expectations about mathematics teaching and learning can be undone in a flash by a student teaching or beginning job experience in a school whose culture promotes order in the classroom, teaching as telling, and standardized test results as the measure of teacher success.

A group at Michigan State (Lappan, Fitzgerald, Phillips, Winter, Lanier, Madsen-Nason, Even, Lee, Smith & Weinberg, 1988) has studied teacher change at the middle grades level in a number of projects. One aspect of teacher change that we have taken very seriously is the challenge of creating environments in which teachers "knowledge" or beliefs about students as learners of mathematics can be challenged. One effective means of challenging teachers beliefs and expectations--and hence, their knowledge about students--has been intensive summer experiences which have a classroom teaching component and long-term follow-up support.

The teacher participants were observers in classrooms taught by the staff. Each of them picked a particular child to study for two weeks. The teachers were to focus on the

cognitive development of their child. What sense were they making of the mathematics? Each day we had a debriefing session at which the teachers talked about their child. It was quite difficult in the beginning for teachers to focus on cognition instead of behavior. They were quick to write students off as not very competent in mathematics. However, as the two weeks passed, every child provided their "teacher observer" with a surprise. Given a chance to listen to children making and defending conjectures about the problem situations being studied, the teachers began to look for more clues as to what the students were thinking.

While this intervention was with experienced teachers, it raises questions about how our teacher education programs, including field experiences, might be constructed. It also underscores the need for the creation of very powerful images of children in the act of making sense of mathematics in order to help teachers learn about students.

Summary

One of our greatest challenges in educating professional teachers is taking seriously the integration of the domains of knowledge on which teachers base their practice. This requires fundamental changes in the ways in which we interact across disciplines within the university and among schools, universities, and the community. Such interactions are difficult. The participants in each of these areas (departments of mathematics, teacher education, educational psychology, schools, communities, business and industry) do not speak the same language nor value the same activities. However, we are all bound by the same moral imperative-- to do the best we can for the children in our communities.

We have a clearer picture of the issues in both pre and inservice work with teachers. We can be guided by the framework from the PSTM on crucial aspects of teacher decision making:

- selecting worthwhile tasks,
- orchestrating classroom discourse,
- creating environments for learning, and
- analyzing teaching and learning.

We have discussed three domains of knowledge that must be considered in the professional development of teachers: knowledge of content, knowledge of pedagogy, and knowledge of students. We have identified teachers' and preservice teachers' deeply held beliefs about

each of these domains of knowledge as part of what needs to be addressed. We have identified time and long-term support, as a critical aspect of change. Current work is giving us promising direction. The challenge is ours. If we want mathematical power for all students, we must find ways to restructure our university programs and to help restructure schools so that teaching becomes the profession to which we are all dedicated.

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Appropriate Technology for Science Education

Beverly Park Woolf, University of Massachusetts

The Opportunity

The National Science Foundation Workshop on Undergraduate Education, November 1992, recommended that appropriate instructional technology be included in undergraduate education, both to enhance instruction and to demonstrate how science and mathematics should be done. However, little definition was given to this recommendation, and few appropriate technologies were explored. This brief document discusses goals and possible studies to implement the recommendation. An example of the use of advanced technology in science education is provided in a paper by Woolf and Cunningham ["Multiple knowledge sources in intelligent teaching systems," in *IEEE Expert* (Piscataway, NJ: Institute of Electrical and Electronics Engineers, 1987)].

The recommendation requires development of programs or task forces to explore ways in which faculty from science, engineering, and mathematics might work with technologists, e.g., computer scientists, engineers, and instructional designers, to develop requirements identifying appropriate technology for doing and teaching science. Participants should focus on questions around how technology should be used within their discipline: What technology will support and provide visualization both of research activities in genetics and the teaching of genetics? How can the science of doing statistics and learning about it be improved by rapid access to data and information? What features of simulations will enhance the teaching and doing of statics, thermodynamics, and dynamics? We seek recommendations, findings, and strategies for defining technology in each science discipline.

NSF and other governmental agencies should focus on the development of informational technology as a mainstream mechanism to improve science education. The scientific, mathematical, technological, and computational literacy of all students needs to be improved: The productivity of the American workforce and supply of students seeking careers in science, mathematics, engineering, and computer technology also need to be increased, and technology can facilitate this activity.

Specific Recommendations

Information science provides an enabling technology for dynamic, interactive, and realistic science education and addresses the heart of the sociological and educational change provided in the information age. Innovative computer technologies should be supported, developed, and realized in practical, large-scale classroom evaluations. A representative sample of recent technologies ready to be applied to education include the following:

- very large instructional knowledge bases
- distributed instructional systems
- intelligent information retrieval systems for instruction
- multimedia networks and operating systems
- scientific databases
- scientific visualization
- management of tutorial dialogue
- machine learning systems to improve system responses
- case-based reasoning for instructional delivery
- representation of pedagogical knowledge.

Network technologies and supercomputers also play a large role in promoting science education. However, the focus at this point should address the intellectual issues about the content of the material used in education before such material is sent over high-speed/high-bandwidth networks.

Rough Plan

Faculty in science disciplines share responsibility with technologists for building technology that addresses the needs of science to prepare teachers for careers in science. Large groups of teachers and students should be involved at the outset. Continuous development, validation, and support of science instructional materials and tools should be monitored within several substantial projects, staffed by both science domain specialists and educators. Basic research in science, mathematics, and engineering at leading universities should be involved and supported as it leads to innovative results applicable to education. Currently such advances are applied to education only as an afterthought. Interestingly, researchers who work with state-of-the-art technology typically ignore these results when teaching their own classes and present their undergraduate courses in the same way their teachers taught them many years earlier. The educational application of basic research is not pursued because development time and large resources are required to apply technology to education. Recommendations, findings, and implementation strategies are needed at the time of basic research to enable scientists and teachers to direct the development of technology to education.

The educational community is traditionally the last to receive innovative technology of any kind; consider application of television and video to the classroom. Currently, information technology innovations are developed in research labs for unrelated purposes and then lightly adapted by industry, including publication and software houses, for education.

NSF and government agencies should focus attention on the development of informational technology as a mainstream mechanism to improve science education in America. Goals should be articulated to increase the quality and relevance of such research. The following three sets of goals are proposed to further explore this issue:

Technological Goals

1. Provide a forum for discussion among science faculty and technologists about the application of basic technology to the doing and teaching of science at the undergraduate level.
2. Review, define, and prioritize several new instructional technologies that might be brought to fruition in both basic and applied research areas.
3. Work with electrical and computer engineers, mechanical engineers, systems designers, network computer scientists, artificial intelligence researchers, and user interface designers to develop technologies for science education.

Instructional Goals

1. Investigate NSF's role in support of the development of instructional tools and pedagogical materials within advanced computer science laboratories.
2. Identify ways that computer scientists and engineers can be mobilized on behalf of education.
3. Identify ways in which NSF can support the training and dissemination of new technology materials on a national scale.

Curriculum Goals

1. Describe programs to support major experiments to develop and use curricula employing advanced technology. Identify several scenarios to integrate this technology in classrooms along with the science, mathematics, and engineering curricula in which computer science research methodologies should first be integrated.
2. Develop numerous full scale courses, with the use of interactive technologies varying age level, subject, and pedagogical strategy. Several technologies should be used extensively with students, and full evaluation

should be conducted to gather information relative to full curriculum development.

3. The government, in connection with the private sector, should make substantial progress in this area by defining an. leveloping appropriate experiments to develop technology for science education.

Reflections on Problems in Secondary School Science and Mathematics Teaching and on the Roles of Computer-Related Technology in Education

David Moursund, University of Oregon

The Problem

1. The country as a whole faces problems, such as the retirement of quite a few teachers in the next decade, a shortage of science and math teachers at the secondary school level, and the continuing problem of a major discrepancy between the subject matter knowledge of people teaching in major universities and people teaching in secondary school.
2. The workload demands placed on secondary school teachers are immense, and the support structure is weak. For example, the typical university professor teaching freshman physics likely has a preparator to set up demonstration equipment to be used in a lecture and lab assistants to set up the labs that students attend. In essence, the concept of a preparator or high-level lab assistant does not exist in high school science. Rather, the high school science teacher is likely to have no help as she/he carries a five-course teaching load (indeed, sometimes a six-course teaching load), where each course meets five times per week.
3. The problems are increased by rapid changes in technology—both within the subject areas and as an aid to teaching and learning. To a large extent, our precollege education system is based on the idea that, once a teacher obtains the necessary initial college education and certificate, almost no additional education is needed. While this might have worked well 100 years ago in a time of relatively slowly changing knowledge in the sciences, it does not work in a time of rapid change as exists now. This problem is exacerbated by the rapid growth of computer-related technology that is useful as a teaching aid, as a general purpose tool, and is routinely built into the instrumentation of scientists. Thus, there is still more for science and mathematics teachers to learn.

Computer-Related Technology in Education Comments

Computer-related technology is potentially a major change agent in both the content and pedagogy of all of education. Clearly, computer-related technology is particularly important in the sciences, mathematics, and engineering.

One of the things that educators know is that, for the most part, teachers teach in the manner in which they have been taught. Thus, it is very important for college teachers to become role models of "appropriate" behavior both in pedagogy and in content. More emphasis should be placed on college teachers' routine use of modern aids to teaching and learning, such as multimedia. Similarly, the potential effect that artificial intelligence (some of the types of ideas that Beverly Woolf demonstrated) could or should have on the content of the curriculum should be explored. It could be that the college-level curriculum is getting out-dated by such

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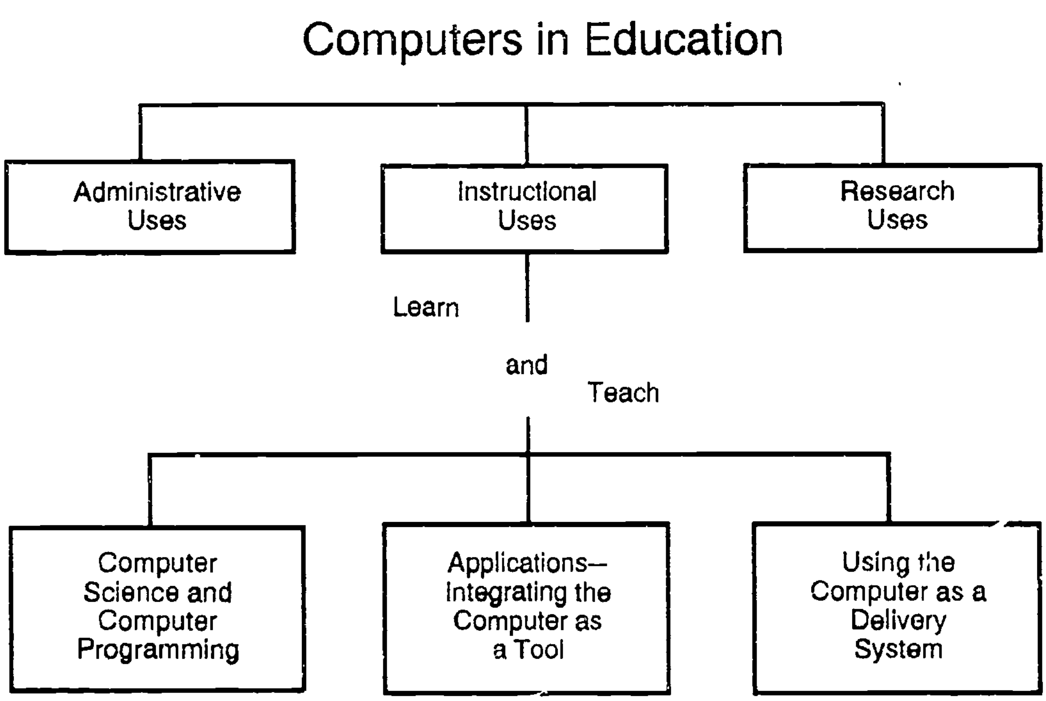
progress in both teaching/learning methodologies and content.

In discussing computer-related technology in education, people often use a diagram such as that on the following page. The three categories of Instructional Uses are relevant to the discussions of our secondary education work group.

1. Computer Science and Computer Programming: Consideration should be given to the nature and extent of computer science and computer programming that the various college disciplines would like their students to have as entering freshmen as well as to how higher education science, mathematics, and engineering departments might contribute to the knowledge of computer science and computer programming of each student who passes through some of their courses.

   Note that this same type of question can come up in other disciplines such as math. It seems clear that most higher education science and engineering departments are unhappy with the math preparation of their students. To what extent do they improve this math preparation in their courses—especially, in a manner that ultimately might lead to improved math education at the precollege level?

2. Applications—Integrating the Computer as a Tool: To what extent do the science, mathematics, and engineering departments routinely integrate tool uses of computers into their curricula, thus helping to prepare all of their students to make routine use of computer as tool if or when they become teachers? My impression is that engineering departments do quite well relative to science and mathe-



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matics departments. Most science and mathematics departments do not exhibit the type of tool use of calculators and computers that the National Council of Teachers of Mathematics recommends in the Standards for precollege math curriculum.

3. Using the Computer as a Delivery System: To what extent do the science, mathematics, and engineering departments make use of computer-assisted learning? The use of computer-assisted learning is growing relatively rapidly at the precollege level. It would have been interesting to discuss whether a similar thing is or should be happening at the college level and the potential effect on higher education. Also, is this change at the precollege level making it more difficult for higher education to exhibit appropriate behavior?

Concluding Remarks

I think the idea that every student is a potential teacher is very important. That is, every science, mathematics, and engineering teacher should hold in mind that each of their students will be a teacher—some in a traditional sense, all will teach themselves, many will teach their children, and most will teach their colleagues on the job. Thus, one component of every course should be a combination of learning theory and pedagogy as it applies to that particular discipline.

Every student needs to be a life-long learner. Thus, every college course should carefully address the issue of "keeping up," the nature of the changes occurring in the field, and how to be a life-long learner. Clearly, this would be useful to potential teachers.

Fast Plants and Bottle Biology

Paul H. Williams, University of Wisconsin—Madison

The development of rapid-cycling brassicas (RCB's) as a research innovation and their introduction into school science classes are an interesting illustration of how biological research can directly influence education. As a plant pathologist at the University of Wisconsin—Madison whose research centered on the development of genetic disease resistance in brassicas, cabbages, mustards, and their relatives, I was continually searching collections of seed from around the world for new sources of disease and pest resistance to breed into new, improved varieties.

While growing plants from brassica seed collections obtained from the United States Department of Agriculture's National Plant Germplasm System (NPGS), I noticed that occasionally one or two plants would flower much earlier than was normal for a particular variety. I became very interested in these rare individuals, and it was then that the idea occurred to me that I might be able to develop, through selective breeding, plants that went through their life cycle much more quickly than the 12 to 14 months that it normally takes a cabbage to grow, flower, and produce seed for the next generation. As a biologist interested in the genetics of underlying disease resistance and in the incorporation of new forms of resistance into desirable varieties, I made slow progress with the brassicas, producing only one or two generations a year.

In 1970, I began in earnest to seek early flowering plants from six distinct but interrelated species in the genus *Brassica*. The species I was interested in were *Brassica oleracea, B. nigra, B. rapa, B. juncea, B. napus* and *B. carinata*. These species represent important economic crops (Table 1), and are interrelated by sharing various genetic information in their chromosomes (Figure 1). Seeds from more than 2,000 accessions from the USDA, NPGS were grown and observed for early flowering and other essential traits that would meet my needs for rapid-

Table 1. Names of Subspecific Taxa of Agriculturally Important Brassicas and Radish

Species (genome)	Subspecies or variety	Cultivar group or common name
Brassica		
nigra (bb = 16)	—	Black mustard
oleracea (cc = 18)	*acephala*	Kales
	alboglabra	Chinese kale
	botrytis	Cauliflower, Heading broccoli
	capitata	Cabbage
	costata	Portuguese cabbage
	gemmifera	Brussels sprouts
	gongylodes	Kohlrabi
	italica	Broccoli, Calabrese
	medullosa	Marrow-stem kale
	palmifolia	Tree cabbage, Jersey kale
	ramosa	Thousand-head kale
	sabauda	Savoy cabbage
	sabellica	Collards
	selensia	Borecole
rapa (aa = 20)	*chinensis*	Pak choi
(syn *campestris*)	*narinosa*	Taatsai
	nipposinica	Mizuna
	oleifera	Turnip rape, Toria
	parachinensis	Saichin, Choy sum
	pekinensis	Chinese cabbage, Petsai
	perviridis	Tendergreen, Komatsuna
	rapifera	Turnip
	trilocularis	Yellow sarson
	utilis	Brocoletto, Broccoli raab
carinata (bbcc = 34)	—	Ethiopian mustard
juncea (aabb = 36)	*capitata*	Head mustard
	crispifolia	Cut-leaf mustard
	faciliflora	Broccoli mustard
	lapitata	Large-petiole mustard
	multiceps	Multishoot mustard
	oleifera	Indian mustard, Raya
	rapifera	Root mustard
	rugosa	Leaf mustard
	spicea	Mustard
	tsa-tsai	Big-stem mustard
napus (aacc = 38)	—	Fodder rape
	oleifera	Oil rape
	rapifera	Swede, Rutabaga
Raphanus		
sativus (rr = 18)	*radicola*	Radish, Dikon
	oleifera	Oil radish
	caudatus	Rattail radish

The haploid complement of chromosomes is a = 10, b = 8, c and r = 9.

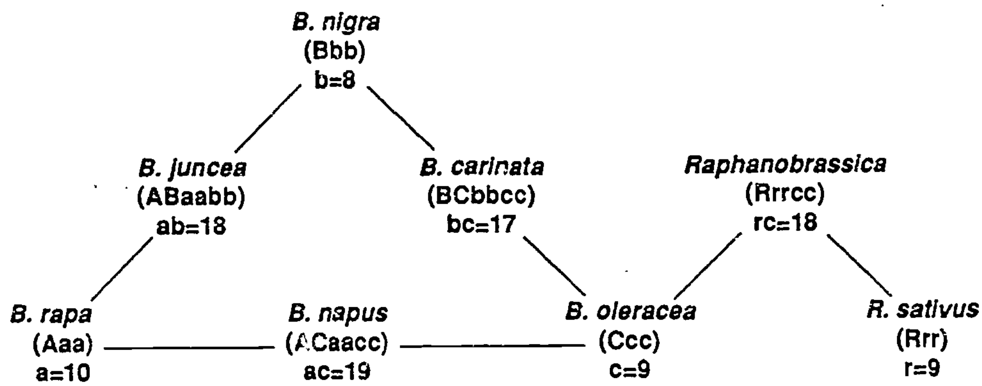

Figure 1. The cytogenetic interrelationships among six brassica species and *Raphanus sativus*. Intergeneric crosses between *R. sativus* and other brassica species are also possible. Cytoplasmic genome is designated by capitals. Nuclear genome is designated by lower case letters, where a = 10 chromosomes; b = 8 chromosomes; c and r = 9 chromosomes.

cycling model plants representing each of the *Brassica* and radish species. Within each species, plants that had characteristics that conformed to what I considered to be ideal, the so-called *ideotype*, were intermated by cross-pollinating them.

The characteristics of the ideotype used for selection of the original parents and successive generations were (1) minimum time from seeding to flowering, (2) petite plant size capable of producing seed at plant densities of approximately 1,000 plants per meter square, (3) high seed set for each pollination, (4) rapid seed development, and (5) absence of seed dormancy. The plants were grown under a set of standard conditions that were chosen for their utility and low cost. Temperature was maintained at 24°C. Soil was a mixture of one part peat moss and one part Vermiculite and fertilized with Hoagland's nutrient mixture. The plants were illuminated continuously from cool white fluorescent lamps with an irradiance of approximately 200 $\mu E\ m^{-2} second^{-1}$. Of the hundreds of plants grown under these defined conditions of environment, only the first 10 percent of the plants to flower and set seed fastest were saved and interpollinated for production of the succeeding generation. Since only the best performing plants were selected for successive generations, genes conditioning the rapid-cycling ideotype increased in frequency in the populations of each species.

Within 8 to 10 generations of recurrent selection, I was able to breed a rapid ideotype of each of six *Brassica* species having life cycles ranging from 35 days for *B. rapa* to 60 days for *B. oleracea* (Table 2). Instead of one, or at best, two generations per year, I could now produce 6 to 10 generation of hundreds of plants under simple fluorescent lights in my office or laboratory. The RCB's became an effective research organism not only for me but for plant scientists throughout the world.

The Crucifer Genetics Cooperative

In order to facilitate the uses of RCB's in plant biology, I established in 1982, the Crucifer Genetics Cooperative (CrGC), a program designed to develop and share RCB genetic stocks and information on their uses in research and education (Williams and Hill, 1986). The CrGC has served over 1450 persons from 56 countries by providing seed, symbionts, and information on the uses of RCB's. Each year new stocks developed by researchers are produced and distributed by the CrGC, and information on their uses is made available through newsletters and information documents (Williams, 1985).

Table 2. Phenotypic Characterization of Rapid-cycling Brassica and Radish Base Populations Grown at 24°C under Continuous High Light.

Species	Genome and chromosome number*	Mean days to flower (SD)	Mean height (cm) to first flower (SD)	Mean seeds per plant (SD)	Days for cycle	Cycles per year
B. rapa	aa = 20	16(1)	11.9(3.1)	78(54)	36	10
B. nigra	bb = 16	20(2)	27.1(4.9)	69(49)	40	9
B. oleracea	cc = 18	30(3)	22.6(5.3)	18(21)	60	6
B. juncea	aabb = 36	19(1)	29.6(4.0)	107(46)	39	9
B. napus	aacc = 38	25(2)	35.3(7.1)	76(53)	55	6
B. carinata	bbcc = 34	26(2)	41.7(6.6)	67(46)	56	6
R. sativus	rr = 18	19			48	7

* Nuclear genome is designated by lower case: a = 10 chromosomes; b = 8 chromosomes; c and r = 9 chromosomes. When grown under lower temperatures and light, development may be delayed. Data are expressed as mean (SD = standard deviation).

Table 3. Educational Topics that can Be Addressed Using RCBr.

1. Growth and development
   a. Seed germination in 2 days, leaf development, stem elongation, flowering (13 to 16 days), fruit (pod) and seed (embryo) maturation
   b. Growth responses
   c. Plant morphology: root, stem, leaf, flower

2. Reproductive biology
   a. Flower development: male and female flower parts
   b. Pollen and pollination: control of pollination, bee sticks
   c. Fertilization
   d. Embryogenesis

3. Genetics
   a. Mendelian: gene expression, dominance, interaction
   b. Mendelian: gene assortment; independence; linkage; F_1, F_2 testcross
   c. Nonmendelian: maternal inheritance
   d. Nonmendelian: continuous variation, quantitative genetics
   e. Selection
   f. Evolution

4. Physiology (mechanisms underlying growth and development)
   a. Using numerous physiological mutants
   b. Growth hormone responders
   c. Photosynthesis: radiant energy utilization
   d. Nutrition: effects of major and minor elements on growth and reproduction
   e. Water relations: excesses and deficiencies
   f. Photoresponses: light intensity, photoperiod and flowering, tropism, etc.

5. Ecology (the plant responding to its environment)
   a. Influences of acid rain on plant growth and development
   b. Effects of air pollution: pollution-sensitive mutant stocks
   c. Chemicals in the plant environment: salt injury, herbicide effects
   d. Effects of pests and diseases on plants
   e. Disease resistance: microbe-plant interactions

Development of Wisconsin Fast Plants (WFP)

An early use of the RCB's was in my plant breeding and genetics classes at the University of Wisconsin—Madison. Rapid-cycling *Brassica rapa* (RCBr) was most suitable for teaching purposes because of its 35-day cycle, compact habit, and abundance of genetic variants. After using RCBr extensively in plant breeding, plant pathology, and organismal biology classes, I realized the potential that these plants had for introducing more plant biology into both the college and precollege curricula. With support from the National Science Foundation, Precollege Instruction Materials Development Program, the Wisconsin Fast Plants Program undertook the development of various genetic stocks and low-cost classroom-friendly growing systems for RCBr that permitted children from kindergarten through college to explore aspects of plant life through hands-on investigative learning.

Critical aspects in the design of Wisconsin Fast Plants growing systems were that they provide individual students the opportunity for growing their own plants and that the system would sustain plants unattended for periods of 4–5 days or longer. Accompanying the growing systems and seed stocks were detailed instructional manuals with a range of open-ended investigations suitable for teachers in elementary, middle, and high school and college (Table 3). Wisconsin Fast Plants Educational kits containing all of the necessary materials for conducting a wide range of classroom activities were patented by the Wisconsin Alumni Research Foundation and licensed to the Carolina Biological Supply Company for distribution.

Fast plants offer teachers and students the opportunity for a broad experimental introduction to plant biology. Normally, students begin their explorations by growing RCBr through a life cycle and producing a crop of seeds. In the course of observing the life cycle students will raise many questions, all of which can serve as the basis for investigative learning activities. Creative and resourceful teachers have found the fast plants ideal for bringing "new life" into their life science curriculum. Many teachers have found fast plants to be an effective activity for engaging students who normally show little interest in science.

The Spiral of Life

The centrality of the life cycle as a framework for investigative learning is reinforced as students come to understand that the life cycle of a fast plant is but one reproductive revolution in an evolutionary continuum known as the *life spiral*. The spiral of life becomes profoundly real for students as they harvest and sow seed, nurture plant growth, accomplish pollination, and observe seed ripening and parental tissues withering and dying. The continuity of life is manifested in seeds, which the students themselves have produced by growing the parents and encouraging pollination between plants that they have chosen. Seeds germinate in less than 12 hours, plants emerge in 48 hours, flower buds appear in 7–8 days, flowers begin to open in 12–13 days, and seeds can be harvested in 36 days (Figure 2).

Students can study many aspects of reproductive biology with RCBr. Floral morphology and its intimate relationship with the honey bee (*Apis mellifera*) provide an excellent example of co-evolutionary interdependence between two organisms. The dissection and close observation of the flower and the honey bee lead to an understanding of the structural relationships between the bee and the flower. Following the dissection, students can explore the remarkably efficient pollen-collecting ability of the bee by making a *bee stick* from the dead bee and using it as a pollination device for their plants. By investigating pollination and the control of pollen germination, students can gain an understanding of the mechanisms that ensure outbreeding of the species. Using clearing techniques and whole mount of ovules, the development of the egg apparatus can be followed prior to fertilization (Smith, 1992). The exploration of endosperm and embryo development following

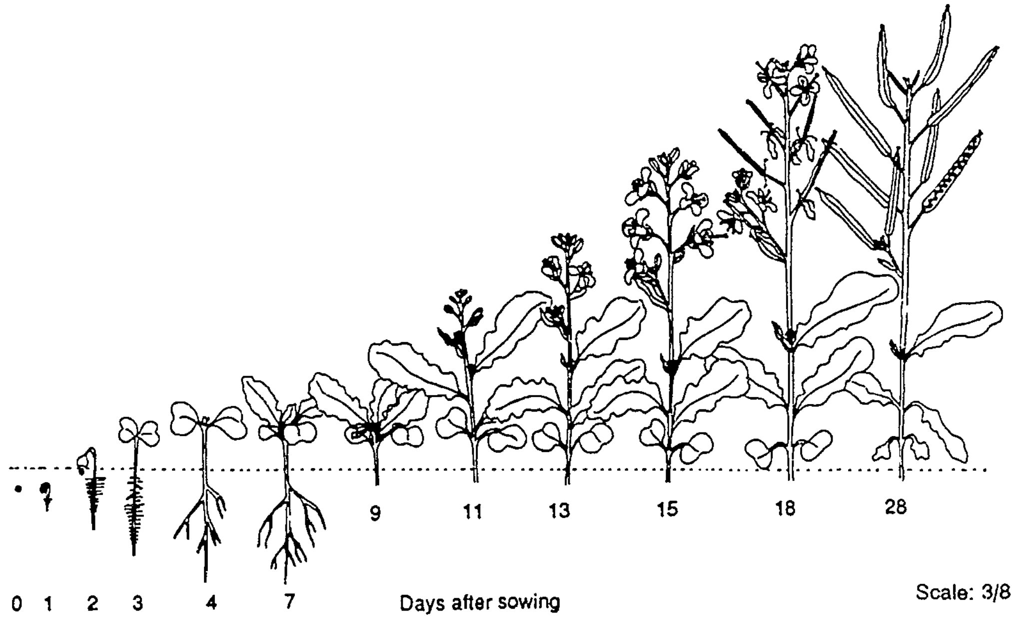

Figure 2. Growth of rapid-cycling *Brassica rapa*, RCBr, showing growth stages at various times from seeding until 28 days.

double fertilization can be a challenging and rewarding experience in learning.

Inheritance, Genetics, Evolution

An understanding of reproductive biology provides a useful setting in which to introduce investigations into the inheritance of variation and the study of genetics. A particularly effective way to begin many studies with RCBr is to have students harvest seeds directly from the dry pod of the prior generation. In doing so, they gain an appreciation of the importance of the maternal parent, the mother, in the establishment of a family structure. All seeds from a pod are siblings by virtue of having a common mother. Groups of students can observe, measure, record, and evaluate characteristics associated with the seed pod such as pod shape, length, number of seeds, etc.—characteristics that can later be compared with similar features on the pods of the sibling plants derived from the harvested seeds. By establishing a family structure, that is by keeping track of the percentage of individuals throughout the growing of a life cycle of fast plants, students are able to investigate the role of inheritance on any particular characteristic that they observe. Patterns of inheritance can be learned through observing variation and experimenting with ways in which the observed variation is inherited. In this way students discover for themselves the underlying principles of inheritance and hence come to learn and understand genetics.

Various RCBr mutant stocks that exhibit a range of phenotypes suitable for studies of Mendelian, quantitative, cytoplasmic, and somatic genetics are available. Genes conditioning the expression of seedling colors including green, purple, yellow-green, white, mottled white and green are easily recognized within 3–4 days after sowing and are thus very suitable for uncovering and understanding the principles of Mendelian genetics. Mutants conditioning the dwarf rosette (*ros*) and tall, elongate internode (*ein*) plant types can be used to investigate the role of the plant growth hormones, the gibberellins, in regulating plant growth and development.

Though the preponderance of genetics taught in school emphasizes Mendelian inheritance, much of the natural variation that is exhibited in plant, animal, and human populations is governed by more complex genetics. For example, the numbers of hairs (trichomes) on the leaves stems and flowers of RCBr varies considerably from plant to plant and is an example of a quantitatively inherited phenotype involving many genes each having a small effect. Hairs are easily counted, and in order for students to understand the basis for variation among individuals in a population, the numbers of hairs counted on each plant needs to be displayed in some organized representation through graphing or statistical treatment. From these organized representations of population features, students gain understanding, which, in turn, leads to questions and further investigations. Many students ask the question: what will happen if we intermate the 10 hairiest plants or the 10 least hairy plants in the class? Will we be able to produce a very hairy population or a hairless population? By understanding the basis for quantitative inheritance such as that conditioning hairs on RCBr, students are better able to understand the genetic basis for the wide ranging variation exhibited in the world around them.

RCBr seed stocks have been developed that are suitable for investigating the cytoplasmically inherited male sterility, associated with the mitochondria, and atrazine herbicide resistance, associated with chloroplasts. These phenotypes are exclusively transmitted in the organellar DNA by the cytoplasm in the egg of the maternal parent. Students' understanding of genetics and evolution are expanded as they learn through experimentation that these cytoplasmically inherited phenotypes cannot be transmitted by pollen. A particularly interesting cytoplasmically inherited stock, known as variegated (Var1), has cells containing mixtures of normal (green), and abnormal (colorless) chloroplasts. The particular balance of normal to abnormal chloroplasts in dividing cells and developing tissues leads to variegated plants with cell lineages having mixed and varying numbers of green and white cells. Variegated plants can give rise to normal green, variegated (mottled white and green) or white plants depending on the mixture of chloroplasts in the egg cell of the maternal parent. The chlorplastic variegation cannot be transmitted through the male, since pollen of *Brassica rapa* does not transmit chloroplasts.

RCBr can provide teachers and students with unusual opportunities for investigating speciation, diversity and domestication. RCBr represents a species that during the process of domestication from the wild has undergone widely divergent selection for a range of forms and uses in widely separated human cultures (Song, Osborn, and Williams, 1988). As illustrated in Table 1, many forms of *B. rapa* exist, from wild and weedy types to succulent head forming and leafy types of oriental vegetables used for cooking, pickling and salads. Large-rooted turnips are used for human and animal fodder while the seed-producing turnip rape is a major source of vegetable oil for cooking and industrial manufacturing. Many of the vegetable forms of *B. rapa* are readily available year around from the grocery sections of most supermarkets and can serve as the basis for a wonderful introduction to the subjects of diversity, speciation, and domestication. When Chinese cabbage, turnip, pak choy, saichin, canola, and RCBr are viewed together (Figure 3), the assertion that they are all the same species generally draws disbelief simply because they look so different. The question then of how these plants that look so different can be the same provides a rich learning experience for students. Each of these vegetable forms can be easily brought into flower directly from the grocery store, then crossed with RCBr to yield a hybrid progeny, F_1, that is unlike either parent. Proof of species similarity comes from the production of fertile, F_2 progeny derived by intercrossing the F_1 hybrid plants. What is most interesting in this activity is to have students grow plants of the parental F_1 and F_2 generations and compare their appearances.

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Students will see how different parents such as RCBr and turnip or Chinese cabbage appear, then how homogeneous the F_1 progeny are. As they observe how much variability reappears among the F_2 individuals, they will again be eager to explore questions they have raised. Students who grow the F_2 seeds of the RCBr–turnip or RCBr–Chinese cabbage crosses should be encouraged to sow seeds in their gardens and to identify plant types that they like. These plants can be sown, flowered, and intermated as the students become bona fide plant breeders!

I have spent considerable time presenting some of the potential Wisconsin Fast Plants as a means of providing students with an experiential understanding of the genetic determinants underlying variability within a single species. Continually influencing the observed phenotype is the influence of environment. The impact of the environment in the expression of the phenotype can be best understood when students are actually involved in growing the plants themselves. I know of no better way for students to gain an understanding of the role of the environment as an interactive partner with genotype in determining the expression of the phenotype than to have them grow RCBr through a life cycle under various environmental conditions.

Physiology

The expression of phenotype in plant growth and development is the domain of plant physiology and plant molecular biology; various physiological mutants of RCBr are available with which to investigate the influence of light, gravity, nutrients, and hormones on plant growth and photosynthesis. Water relations and photoresponses can also be studied.

Ecology

Exploring how RCBr plants respond to changes in their environment can provide the basis for interesting experiments in ecology. Variation in the acidity of precipitation, water salinity, chemical composition of soil, and atmosphere in which the plants are growing all provide excellent avenues for exploratory learning. By growing plants in cages and containers, students can examine the effects of various pests and disease organisms on plant growth.

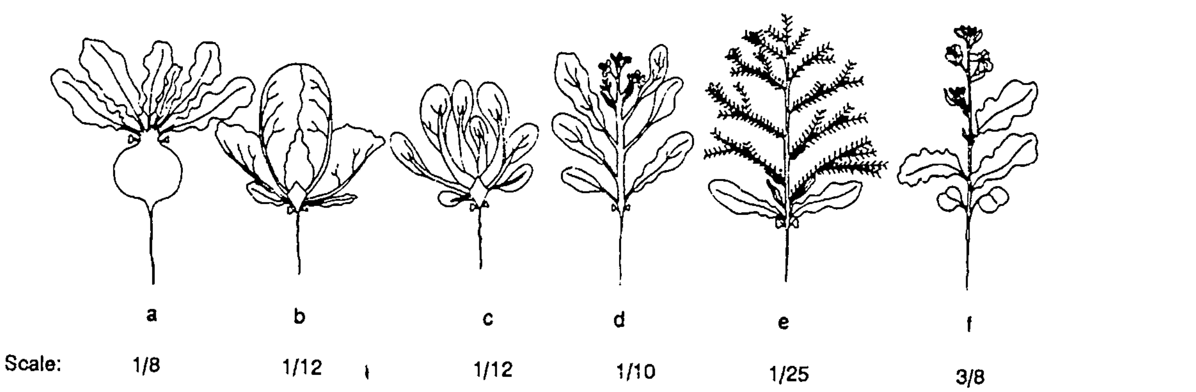

Figure 3. Forms of *Brassica rapa* representing various cultivar groups: (a) *B. rapa*, turnip group; (b) *B. rapa*, Chinese cabbage group; (c) *B. rapa*, pak choi group; (d) *B. rapa*, saichin group; (e) *B. rapa*, turnip rape group; and (f) *B. rapa*, rapid cycling.

Characteristics of the Wisconsin Fast Plants Program

From the above discussion, it can be seen that Wisconsin Fast Plants Program offers content- and context-rich open-ended learning experiences. Instructional materials are designed to introduce teachers and students to the general topic area to be learned by providing them with sufficient background information to be comfortable with initiating an exploration. Once teachers and students begin to explore, they are encouraged to proceed through a science process that emphasizes observing, questioning, problem posing, and hypothesis generation and testing. Experimental design, execution, analysis, and communication of the results are important aspects of the process of science.

Because of the rich genetic background underlying many of the RCBr stocks, teachers are encouraged to have students consider the genetic implications of their exploration. Emphasis is placed on quantifying observations and experimental results. Mathematics and statistics are important partners in many Wisconsin Fast Plants (WFP) explorations.

Bottle Biology: A Technological Partner for Fast Plants

An early consideration in the WFP instructional materials program was the development of low-cost equipment that would lower the barrier of expense associated with experimentation. The Bottle Biology Project (BB) was undertaken, with support of the National Science Foundation, to instruct teachers and students in ways to construct most of their experimental equipment from plastic soda bottles, food containers, and film canisters. Under the Bottle Biology Project, Fast Plant growing systems and a wide range of experimental equipment for investigating germination tropisms, respiration, nutrition, pollination, ecology, and many other aspects of biology were designed and tested. Directions for the construction of many pieces of experimental equipment have been made available through information documents, newsletters, and manuals of WFP and BB. With support from the W.K. Kellogg Foundation, Fast Plants and Bottle Biology have been used in the development of a number of classroom investigations emphasizing agricultural and ecologically based science activities. These agriscience materials were created and tested by 20 teams of biology and vocational agriculture teachers from school districts around the U.S. and are being prepared for publication.

Dissemination of Wisconsin Fast Plants and Bottle Biology

From early conceptualization the WFP and BB Programs have emphasized the need for high-quality, low-cost, easily accessible, hands-on materials, most of which could be created or produced by teachers and students. The WFP and BB materials have lent themselves to modification and adoption into many curricula being developed in schools, districts, and educational programs across the United States and abroad.

An important element in the dissemination of the Wisconsin Fast Plants, Bottle Biology, and Agriscience material, in addition to the quality of the science they bring to the classroom has been the strong emphasis on quality teacher inservice workshops supporting the use of the materials. Two-day inservice workshops are given in October and February each year at the University of Wisconsin—Madison. With support from the NSF, nine regional training teams located at major urban centers throughout the U.S. have continued inservicing teachers from school districts in their regions. Training teams are composed of master teachers at all levels from elementary through college, scientists and science supervisors. Teacher-trainers and all teachers attending inservice workshops receive twice yearly the *Wisconsin Fast Plants / Bottle Biology Notes*, a newsletter rich in new ideas and information for life science investigations. A WFP/BB/Agriscience booth at regional and national meetings of science and vocational agriculture teachers has stimulated a growing interest among teachers for these materials.

Future Direction for WFP and Bottle Biology

With continuing support from the NSF, the WFP/BB programs are developing inservice workshop training kits to enable teachers, scientists, educators, and administrators who have become excited over the value of Fast Plants and Bottle Biology to further train teachers in their communities. Persons having some experience with these materials will now be able to train teachers in their communities by requesting inservice workshop kits from the WFP Program. Kits will contain all of the necessary materials to conduct an inservice workshop of a specified length for a specified number of teachers. The program is thus supporting the model that appears to have been initially successful, namely that of having experienced, exciting teachers further training teachers.

Closing the Loop: Preservice Training and Research Experiences

Just as they are suitable as models for research in many areas in plant biology, so the Fast Plants, when partnered with the technology of Bottle Biology, provide an ideal medium for the training of future teachers. The potential for Bottle Biology and Fast Plant materials in science methods courses is very great. Increasingly the materials are being used in college and university biology classes where many future science teachers are being trained.

Perhaps the greatest potential for Fast Plants and Bottle Biology is as materials for preservice and inservice teachers who as part of their training desire a bona fide research experience. Recently, I have initiated a program at the University of Wisconsin—Madison, in which preservice science education majors may participate in a research project with RCBr in my laboratory. Based on a question of interest to them, students develop a research plan using RCBr and Bottle Technology. Over the period of a semester or two and a summer, they conduct their research in my laboratory working with plant pathology graduate students and postdoctoral visitors. An important outcome of their research is the conversion of it into effective instructional material which they may evaluate in their own classroom, present to their peers, and publish in a science or science education journal. Though my experience with this preservice research model is limited, I have found that both undergraduates and teachers who have had a meaningful research experience in a biology laboratory bring new and rich insight into their science classrooms.

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Workshop Day II: Disciplinary Panels

Judith Taack Lanier, Michigan State University, Co-Chair

The Role of Chemistry Faculty in the Undergraduate Education of Science and Mathematics Teachers

Phillip R. Certain, University of Wisconsin—Madison, Chair

Panel Members: Audrey B. Champagne (SUNY at Albany), Alan H. Cowley (The University of Texas at Austin), Henry Heikkinen (University of Northern Colorado), Harry P. Hopkins (Georgia State University), Adrienne W. Kozlowski (Central Connecticut State University), Ivan Legg (Memphis State University), Jesse Nicholson (Howard University), Patricia L. Samuel (Boston University), Barbara Sawrey (University of California, San Diego), Sylvia Ware (American Chemical Society), Vera Zdravkovich (Prince George's Community College)

I. *Overview from the Chemistry Group*

The chemistry community, primarily through the activities of the American Chemical Society (ACS) and through projects sponsored by the National Science Foundation, has a distinguished record of involvement in elementary and secondary education. What is needed is progress at the departmental level within colleges and universities in linking the undergraduate chemistry curriculum to the education of elementary and secondary school teachers.

Chemistry faculty in general readily accept responsibility for teacher education in chemistry at the rational level. The challenge is to put this acceptance into practice. Whatever is done to improve teacher education and advance diversity will improve education for *all* students.

The Chemistry Panel presents the following recommendations in the areas covered by the thematic panels:

Instructional Innovation: Recommendations

- Innovative methods (such as computerized office hours and collaborative learning groups) to increase student-faculty interactions in large lecture courses should be encouraged.
- Within each course, chemical facts and concepts ought not to be presented in isolation. The interrelationship, the connectedness, the significance, and the rationale for their inclusion should be made clear.
- NSF and other granting agencies should call a workshop of academic leaders—provosts, presidents, and vice presidents—to explore mechanisms for changing the faculty culture by supporting and rewarding educational innovation.
- NSF and other granting agencies should consider asking institutions receiving outside

funds to allocate some part of overhead to education innovation and improvement.

Valuing Diversity in the Educational Process: Recommendations

- Diversity should be recognized as a resource, not as a problem. Diversity should be broadly defined to include differences in level of students' preparation, their goals and aspirations, and their learning styles.
- A variety of learning materials, resources, environments, and assistance should be provided to help all students reach their potential.
- The pedagogy involved in teaching to diverse populations is equally as important as the discipline of chemistry.
- Both science faculty and prospective teachers need to develop a broad repertoire of teaching techniques. Small-group activities are particularly useful in meeting this goal.

Research on Learning and Teaching Science and Mathematics: Recommendations

- Collaboration is needed between the teachers of chemistry and the members of the educational research community.
- Departments of chemistry should encourage faculty to be involved in educational research.
- The ACS should stimulate the dissemination of educational research (e.g., workshops at regional and national meetings).

Assessment: Recommendations

- Assessment should be used to improve student learning.
- Assessment of students should be used as a driver to encourage them to use higher levels of cognition.
- A variety of assessment techniques should be used, including group tests, essay questions with both large and small classes, concept inventories, problem-solving strategies, and portfolios.
- Collaborative efforts and alliances between research universities, liberal arts colleges, two-year institutions, and precollege teachers should be encouraged to address the effectiveness and excellence of undergraduate chemistry teaching.

Prospective Elementary and Middle School Teachers: Recommendations

- Existing efforts and programs of the chemistry community including the ACS should be recognized, built upon, and disseminated.
- The chemistry community should be supportive of teachers in introducing more chemistry into the elementary curriculum.
- Middle school science teachers are science specialists and must be educated as such.
- Over the long haul, improvements in teacher training (e.g., by developing discovery method laboratories) will improve education for all students.
- Conversely, undergraduate chemistry courses should strengthen the laboratory component to address the needs of all students including prospective teachers.

Prospective Secondary School Teachers: Recommendations

- Existing guidelines for preparation of chemistry teachers (ACS, National Science Teachers Association) should be critically reviewed and strengthened as appropriate in consultation with the larger chemistry community.
- National software standards for educational technology should be developed as a prerequisite for widespread use in the classroom. Simulations of laboratory experiments should be used for laboratory extension, not for laboratory replacement.
- Undergraduate chemistry courses should strengthen the laboratory component to address the needs of all students including teachers.

- The ACS should continue to encourage current and prospective chemistry teachers to be involved in the activities of the profession.
- Chemistry faculty should ensure that prospective chemistry teachers are introduced to and encouraged to become active in ACS and other professional networks.
- Teachers must be afforded time and support for professional development through societies (ACS) and programs.
- Chemistry faculty should ensure that prospective teachers develop a powerful repertoire of subject-specific teaching techniques, including demonstrations, interactive techniques, and appropriate use of technology. Prospective teachers need information about procurement and disposal, safety, and the use of inexpensive and readily available materials.
- The undergraduate chemistry curriculum for all students, including future secondary teachers, should make explicit the logic and cohesiveness of modern chemistry and related bridging disciplines, to provide a broad context from which to evaluate the relative importance of specific models and theories in chemistry as well as their relationship to each other.
- Students must also have a broad exposure to applied chemistry throughout the curriculum.

II. Reports from Thematic Group Representatives

A. Instructional Innovation

Barbara Sawrey, Reporter

The panel presentations addressed innovative techniques that could be applied to classes of any size, but a number of them had been used successfully in large classes, thus making them of interest to those of us teaching introductory chemistry courses. It was agreed that by improving introductory courses in all the sciences, we would benefit both science majors and non-science-majors alike. Students who have chosen, or will choose, teaching careers in elementary, middle, or secondary schools may be in either category. Of course, graduate students, as teaching assistants, also gain from being part of the innovations and improved instruction.

The presenters agreed that innovation in the college classroom did not necessarily require a large infusion of money, but rather time. Often that time could only be acquired through awarding money to faculty, because the time is needed to think, develop strategies, and evaluate the effects of things tried. The dissemination of results of innovation experiments in the classroom (both successful and unsuccessful) to our less interested colleagues was seen to be a major stumbling block to the promulgation of ideas. Some incentive may likely be required to sway those researchers who are not rewarded for their interest in teaching or ability to teach.

The six presentations covered the areas of collaborative learning, open-ended inquiry in a laboratory setting, computerized office hours, allowing students to confer in small groups in order to predict outcomes of in-class demonstrations, and having students take an active part in presenting the science they've learned to a younger audience as part of a class project. All strived to increase and enhance faculty/student interaction in some way and generate enthusiasm for science.

The panel did a lot of hands-on small-group exercises of the sort students would do. Even panel members who could be called hardcore resistors or curmudgeons began to soften to the approach as we found ourselves forced to break away from the independent, I-must-solve-this-by-myself strategy. Over the course of the day we became cooperative, become better listeners, and formed a community spirit, much as we would want our students to do.

The panel agreed on the following recommendations, some of which should be familiar to chemists:

- There exists a tension between content and process in the classroom. With the flood of information available to all of us, we should

be more concerned with teaching students how to learn all the new material they need, rather than telling them what it is.

- Textbooks may or may not be the way to convey course material in the future. A modular approach provides more flexibility.
- Computers are effective additions to our repertoire of educational tools when used appropriately. It need not cost a lot of money to make some use of educational technology. Most of us do not make full use of the facilities available to us at present.
- The reward system for faculty must change to allow teaching to count more in the tenure and review process and to acknowledge the credibility of science education research as a scholarly activity.

We also discussed, but disagreed on, at least one item:

- There was a suggestion that the NSF could couple the award of research dollars to education of undergraduates in some way. Most of us could not see a practical, enforceable way of doing this.

Overall we concluded that the good role model that was provided by the faculty member who cared enough to try overcoming the disadvantages inherent in the large classes was one that benefits the undergraduates and the teaching assistants too, both of whom are potential future teachers.

Clearly the faculty in the science departments must work more closely with their colleagues in the education departments and assume some of the responsibility for what is being taught in the country's schools by teachers who were once our students.

B. Valuing Diversity in the Educational Process

Adrienne W. Kozlowski, Reporter

This panel emphasized that diversity of many kinds is present in our classrooms: that of aspirations, interests, preparation, and learning styles, as well as the more traditional ones of age, gender, ethnicity, and culture. By offering a wider variety of teaching styles and emphasizing peer teaching and learning in lecture as well as laboratory, faculty can make chemistry more rewarding to a larger group of students. Prospective teachers will not be the only beneficiaries of change.

The chemistry education community is poised for change. There has already been much discussion on the need for revamping the introductory and general chemistry programs. Much of this has focused on appropriate content. At least equal attention should be paid to the method of delivery. Chemistry faculty should be encouraged to adopt a more varied approach with less lecturing. They need to become experienced in and comfortable with a variety of ways of helping students become more active participants in their learning. Effective group activities could include peer conversations to clarify materials presented in lecture, group assignments or projects, or lab activities requiring more cooperation. Students need to feel connected to the process of actively learning. When such techniques become the norm, prospective teachers will have appropriate models to use in developing their own teaching strategies—they will have seen a diversity of teaching styles that address a diversity of learning styles.

Professional societies, ACS in particular, and colleges and universities need to offer opportunities to faculty to become familiar with techniques for changing their teaching styles and to support networks for getting these changes into the classroom. Faculty already juggling teaching and research need streamlined access to techniques of implementing change.

By construing diversity broadly, the panelists emphasized that valuing diversity is the same as making sure that every student finds a niche in the learning environment that offers success. When I was assigned to the panel on diversity, I felt somewhat intimidated; but I emerged from the working sessions with a new perspective and enthusiasm for implementing the recommenda-

tions that have already appeared earlier in this document. I wish to encourage faculty members to take the initial steps to change from a lecture style to a group interactive format. It is a challenge, but there are rewards for the professor, the students, and the prospective teacher. Much can be done that will improve the education of teachers.

C. Research on Learning and Teaching Science and Mathematics

Harry P. Hopkins, Reporter

Educational research on the cognitive process in science and mathematics has recently provided many new insights into learning science and how the learner develops concepts. Much of this new information has not reached the chemical education community, and very little of the research was performed in a chemical context.

The teaching of chemistry and chemical concepts could benefit greatly from new educational research on how basic constructs are developed in the learner's mind. Such work probably cannot be performed adequately by members of the arts and science community without interacting with established members of the educational research community. Collaborative research on how chemical concepts and problem solving in this area are developed by the learner is essential for the improvement of chemical education.

These efforts would be particularly beneficial for developing better methods for presentation at the elementary and secondary level, where the learner has not yet gained sophistication. In order to think adequately in the chemical context, a person has to use abstract thinking that cannot be readily related to everyday experience. How can teachers of chemistry introduce abstract concepts that cannot be related to everyday experience? The effects of a chemical reaction can usually be presented and understood, but diagraming such a reaction and the principles for predicting it are grounded in abstractions.

Developing new approaches to presenting chemical formulas to students and developing new methods for students to explore how and why chemical reactions happen is a challenging task. Educational research will provide many insights in these areas if the members of the chemical community are willing to embrace methods of educational research.

A pertinent question is "can students learn chemistry and related concepts without the aid of lectures?" The inquiry method has been proven to be a powerful tool in mathematics and physics, but will this method be adequate to develop chemical reasoning in students?

D. Assessment and Evaluation as a Means to Enhance Learning

Patricia L. Samuel, Reporter

A number of nontraditional methods for assessing student learning were presented and discussed by the panel members. The descriptions that follow reflect what I believe would be useful to chemistry faculty as we attempt to help our students learn. Effective assessment is a particular problem for instructors of large courses. Several of these testing strategies are readily adaptable to the large course.

Problem-Solving Strategy Questions

Asking students to describe their strategy for solving a quantitative problem can encourage them to think about the problem in a different way than they would if asked to solve it for a numerical answer. When answering a strategy question, they cannot calculate first and think later. One format for this type of question asks the student to describe the entire strategy: identification of the concepts needed and the reason for each concept, accompanied by a thorough explanation of how to apply these concepts to the problem. Another format would be to ask the student to select the most important concept needed for a problem from a list.

Problem-solving strategy questions enhance student learning when used in combination with traditional questions. Data were presented that indicated that students who had been required to

write out strategies performed better on a traditional final examination than a control group of students who had not.

Concept Inventory

A type of test called a concept inventory can be used to find out what students believe about scientific concepts. This information is particularly useful for diagnosing student misconceptions. In order for learning to occur, students must replace their misconceptions with correct understanding of concepts.

To design a concept inventory, the instructor first identifies some fundamental concepts; for chemistry these might be the mole, bonding, or chemical equilibrium. For a particular concept, one then lists its dimensions or components along with common student misconceptions. Then questions can be devised that probe student understanding of the concept.

An example from physics, the force concept inventory, was described. The testing instrument has a multiple-choice format, so that it is easy to administer and evaluate. The concept inventory can be used

- to convince faculty that a learning problem exists, i.e., student understanding versus rote memorization;
- to evaluate instruction by using it as a pretest and a posttest;
- to diagnose student misconceptions.

The presenter does not recommend using the concept inventory directly as a teaching tool; that is, just telling one's students that misconceptions are wrong does not change the students' beliefs. He favors teaching in a way that encourages students to construct knowledge actively, and in so doing, replace their misconceptions with correct ideas.

The presenter stated that he had found the diagnostic function to be particularly helpful to graduate students. One application of the concept inventory is to use it as part of a training program for teaching assistants. It could also be useful to undergraduate students as they prepare to take advanced courses.

Essay Questions with Large Classes

The essay, or free response, examination question is usually regarded by instructors of large courses as an unattainable dream. Thus it was a pleasure to hear that it is, in fact, quite possible to include this type of question in classes with hundreds of students in which examinations are graded primarily by teaching assistants.

The presenter was for several years the faculty member responsible for directing the grading of the Advanced Placement (AP) biology examination. She has successfully transported the grading methods used for the AP exam to her large undergraduate biology courses. The key to successful grading of essay questions under these conditions is for the graders to meet together to establish standards for each question. Standards are the components of a good answer. The graders must first decide what constitutes a good answer and then assign a weight to each standard. I was very encouraged by this presentation and plan to try the method with my own large class.

Group Tests

A group test or quiz is one that is taken together by two or three students who submit a common answer. Each member of the group receives the same grade. The presenter demonstrated this testing method by asking the panel members to participate in a group test. She also provided student answers to the question. Each member of a group first attempted to answer the question individually, then the group assembled to discuss the answers and come to an agreement on which answer was best.

The advantages of the group test are

- Students can learn from one another, which helps those students who act as teachers to learn as well as their partners or group members.

- It can reduce competitiveness among students and foster the notion that they are in the course to learn, not merely to get a grade.

A disadvantage is that a weak and lazy student may not do the work, even after several weeks, thus putting most of the responsibility for learning on the better students. The instructor can help solve this problem by adjusting the composition of the pairs or groups, perhaps putting the lazy students together.

Student Portfolios

A portfolio is a collection of student work and related material that has been selected by the student to demonstrate his or her progress in learning. Each item in the portfolio is labeled with a caption that explains its nature and function. This caption is crucial to the usefulness of the portfolio as an assessment tool, for without it the collection becomes a scrapbook. Portfolios are normall\ used as one of several assessment methods.

To use portfolios as an assessment tool, the instructor must first decide what the goals of the course are and articulate these in sufficient detail so that students can understand them and thus choose material for their portfolios. For example, a goal could be that students learn how to ask good questions and to integrate existing data. The process of delineation of course goals can be a difficult task, especially for college and university instructors, but it is an essential one. Portfolios would be especially effective in assessing a student's growth and change during a year-long course, or over a period of several years.

E. Experiences for Elementary and Middle School Teachers

Alan H. Cowley, Reporter

The major themes discussed by the Thematic Panel on Prospective Elementary and Middle School Teachers were as follows:

Pedagogical Issues

One of the issues discussed by the panel concerned the question of whether special science and mathematics courses should be provided for elementary and middle school teachers. The opinion of the panel was divided on this question. The representatives from the sciences expressed the view that their teachers should take the same courses as science majors while the representatives from mathematics believed that special courses are required for their teachers. The basis of this viewpoint was that future mathematics teachers require exposure to several specialized teaching techniques that would not be of particular interest to the mathematics major. A second somewhat related pedagogical issue relevant to the question as to whether future elementary and middle school teachers should be trained separately. The unanimous view of the panel was that they should. In arriving at this opinion, the panel recognized that the future middle school teacher requires much more mathematics and science than the future elementary school teacher. In effect, the future middle school teacher should be a mathematics/science specialist, while the future elementary school teacher should be a generalist.

Strategies for Improving Teacher Education at the Universities

There was a general statement that a more interdisciplinary approach is needed for the preparation of mathematics and science teachers. The view was expressed that such changes can be brought about most effectively by the development of interdisciplinary laboratory courses. The implied strategy is that such changes in laboratory courses will generate enthusiasm for changes in the lecture courses. Integrated science laboratory courses are, in fact, being developed. Two programs of this type were discussed: a chemistry/botany laboratory and a chemistry/zoology laboratory.

Apart from student evaluations, faculty at major universities are not subject to frequent assessment, nor do they receive significant training in teaching and learning methods. The panel was of the opinion that more effort should be devoted to the integration of course content and pedagogy. Strongly coupled to this question was the issue of developing a reward structure for those faculty from the disciplines who devote a significant fraction of their time and effort to mathematics and science education.

More use should be made of the professional societies. Many scientific societies such as the ACS have developed programs that can be built upon and disseminated both in the universities and in the teaching profession.

Content and Philosophy of Courses

The panel was in agreement that significant improvements are needed, particularly in the laboratory offerings, but also in the lecture courses. The approaches should be observational and discovery active. Also, more emphasis should be placed on collaborative problem solving rather than working exclusively on an individual basis.

Finally, for new teachers to develop more familiarity with "real world" problems, it was recommended that, after practice teaching, they take a course on science and technology issues of interest to society.

F. Experiences for Secondary School Teachers
Vera Zdravkovich, Reporter

Vera Zdravkovich served as the reporter for the panel. Her summary of panel discussions, which she shared with the Chemistry Panel, appear as the introduction to the chapter, "Experiences for Secondary School Teachers," page 160.

The Role of Engineering and Computer Science Faculty in the Undergraduate Education of Science and Mathematics Teachers

Mario J. Gonzalez, The University of Texas at Austin, Chair

Panel Members: Thomas Henderson (Southern University), Gretchen Kalonji (University of Washington), Don Kirk (San Jose State University), Pamela Mack (Morgan State University), Susan M. Merritt (Pace University), George P. Moore, David Moursund (ISTE), Karan Watson (Texas A&M University), John Werth (The University of Texas at Austin), C. Roger Westgate (Johns Hopkins University)

I. Charge to the Engineering/ Computer Science (E/CS) Disciplinary Group

As stated in the letter of invitation to workshop participants, the workshop "... will consider approaches that disciplinary faculty believe can be effective in preparing prospective teachers, and develop strategies for faculty from the arts and sciences to play a larger and more effective role in the education of prospective teachers."

Members of the E/CS group observed that they were at somewhat of a disadvantage in this workshop in that prospective teachers do not normally take courses offered by E/CS faculty. That is, most E/CS faculty members have little or no contact with prospective teachers in a structured educational environment. This observation and its implications led to comments and recommendations (see Section III) that seek to create new bases for interaction rather than to refine or improve existing situations.

One member of the E/CS group was assigned to each thematic group. That individual was also charged with preparing a summary report of the thematic group meeting with the following constraint: the summary report should focus on those aspects of the thematic group meeting that are applicable to the E/CS group.

II. Reports from Thematic Group Representatives

A. Instructional Innovation

Mario J. Gonzalez, Reporter

BASIC PROBLEM: Engineering educators do not normally come into contact with prospective teachers. With respect to the goals of this workshop, therefore, we are at a disadvantage when compared with our colleagues in the sciences and mathematics.

QUESTION: Should we offer courses that teachers can take?

1. Community college faculty member arranges for students in her science classes to satisfy some course requirements by making science presentations to students in K–6.

   a. Some K–6 students may be motivated to pursue projects in depth to an extent that they may choose to study science and mathematics in college.
   b. Community college project team members may decide to become teachers.
   c. The teachers of the K–6 students may develop new mathematics or science interests and become better teachers.

   POSSIBLE ACTION: We can do something similar with students in our classes and engineering students who are members of engineering student organizations.

2. Science and mathematics professionals and professional societies need to get involved in curriculum development and in preparing K–12 textbooks and they should be rewarded for it.

   POSSIBLE ACTION:

   a. Work with state education boards
   b. Work with own faculty senate
   c. Seek institutional, college, faculty endorsement

B. Valuing Diversity in the Educational Process

Gretchen Kalonji, Reporter

Our panel on valuing diversity, itself quite impressively diverse, was able to come to a consensus about a variety of issues. First of all, we agreed that diversity should be interpreted in a very broad sense, encompassing not only ethnic, racial, and gender differences, but diversity in learning styles, experience, and aspirations.

We shared in a number of stimulating activities, which gave concrete examples of using diversity to enrich education. Two main principles jelled from these activities. The first is that, as faculty members, we must mirror in our practice the type of diversity we hope to encourage others to value. That is, we have to work to provide a diversity of paths to mastery of our disciplines, so that all of our students can contribute to the intellectual health of our communities. The second tenet is that if faculty members are truly to foster diversity and learn to view it as a resource and not a problem, they will need assistance in coming to grips with pervasive existing biases and hierarchies.

The centrality of employing a diversity of teaching strategies in college science, math, and engineering courses was stressed by our panel. We saw examples of a number of classes which were structured explicitly to provide diverse ways for learning and excelling, using a rich repertoire of teaching and assessment methods to ensure that all students can thrive. These diversified teaching strategies can simultaneously provide potential future teachers with an appreciation for diversity as a resource, as well as some practical experience in ways of encouraging it. We recognize that not all of the practices that faculties employ in their science and engineering classes will be appropriate for K–12 learners; nevertheless, we believe that faculty members can provide a great deal of relevant, practical experience in creating diverse learning environments in their disciplines.

One of the most important strategies to utilize and model is the development of student learning communities designed to promote *deep* immersion in the culture of our disciplines and aimed explicitly at very high standards of accomplishment. An important component of that strategy is to find ways of broadening the scope of the discourse in our classes. In a number of our presentations, the value of writing for science, mathematics, and engineering concept development, of small-group discussions processes, and of student research team formation were all stressed.

Another common theme was the need to make connections to the students' larger lives.

We need to recast the traditional content into larger contexts that focus on major themes, critical thinking, and ethical and social issues. The desirability of bringing teams of faculty together to create new courses across disciplinary lines was also emphasized.

In addition to the activities mentioned above, our panel believed there is a need to involve science, math, and engineering faculties more deeply in explicit, subject-matter-specific teacher training. Such involvement would include sharing of powerful demonstrations and activities, plugging into professional discipline-based networks, and collaboration with education faculty in the design and teaching of new courses.

In summary, we believed that there *are* powerful roles that faculty can and must play in helping future teachers learn to create mechanisms for valuing diversity. We believed that the strategies for doing so will vary greatly from discipline to discipline and looked forward to the discipline-based groups as a forum for generating more concrete recommendations.

C. Research on Learning and Teaching Science and Mathematics

John Werth, Reporter

A key issue discussed was the lack of interaction between the science disciplines and education research. This lack of interaction is seen in many different areas. Some examples are:

1. Many discipline faculty members do not know much about educational research or use it in their teaching.
2. Some discipline faculty members perceive that educational research is hard to apply, that consequences of the research are difficult to understand, and that it is inconclusive. These attitudes are at least partly rooted in the lack of knowledge implicit in point 1 above.
3. There is not a suitable level of trust and understanding on either side about quality of work, interest in applying the research, or its relevance.
4. Model curricula of the discipline professional societies often do not rely on the findings of educational research.

The group had a number of ideas about how this problem might be addressed. Some of these were the following:

1. Developing workshops to expose discipline faculty to educational research.
2. Encouraging discipline faculty to become engaged in educational research.
3. Facilitating the interaction of educational researchers and discipline faculty with the goal of exposing educational researchers to the practical concerns of faculty.

Part of the session was taken up in presenting current ideas from educational research. Though none of these presentations directly addressed either computer science or engineering, there were valuable insights about possible educational strategies. In particular, the following ideas seemed to raise questions about traditional teaching practices in computer science and engineering:

1. Reducing the role of lectures in teaching and enhancing the direct student experiences in class.
2. Emphasizing student collaboration.
3. Addressing student misconceptions, especially about the application of science to "real world" situations.

These ideas seem likely to lead to an increased emphasis on some variant of the laboratory concept. However, there is a fair amount of research that shows that traditional labs associated with lecture classes do not significantly affect concept comprehension. All this seems to indicate that there is still substantial research left to do on how to apply these ideas in the "real" classroom. Developments in this area might especially affect teaching and teacher training in computer science and engineering because of their focus on applying science to the world and

because of their already heavy reliance on laboratory work.

An important theme in current educational research is that teaching and learning have significant discipline-specific content. Consequently, one way to make progress is to encourage discipline faculty to become involved in educational research. The group recommended that NSF try to find ways to encourage this activity.

D. Assessment and Evaluation as a Means to Enhance Learning

Don Kirk, Reporter

The Assessment and Education Thematic Workshop was concerned with a diversity of assessment modes used in a variety of course and curriculum settings. Some of these assessment approaches were developed in response to the need to evaluate a new course/curriculum. An example is the Computer Intensive Algebra (CIA) Curriculum [Heid, M.K.; Shets, C.; Matras, M.; Menasian, J. "Classroom and computer laboratory interaction in a computer intensive algebra curriculum." Presented at the April 1988 meeting of the American Educational Research Association, New Orleans, Louisiana], in which calculations with symbolic manipulation capability are used by students, thus enabling more consideration to be given to modeling real world problems, conducting explorations, and interpreting results. Student interviews were used extensively in evaluating this curriculum.

In another situation, described by David Hestenes of Arizona State University, the results gained from an alternative assessment method pointed to a different instructional strategy. He led an effort that culminated in the development of a concept inventory for mechanics knowledge in physics. Used at a variety of levels, this inventory led to the development of a modified instructional approach in use in Arizona high schools. It is a laboratory-based approach with no lectures, and student performance improvement, while not uniformly high, is encouraging.

The Workshop recommended that a variety of assessment procedures be used to evaluate student learning. In addition to student interviews and the concept inventory, others described were as follows: portfolios of student work; self- and group-assessment of their performance by students; use of essay questions; and qualitative strategies for problem solving. These assessment methods are intended to be meaningful to students by helping them relate subject matter to real life problems and by assisting them in identifying their ability to apply knowledge and processes to novel situations. In addition, these measures should inform teachers by revealing student misconceptions, being responsive to different learning styles, and providing insight into student understanding.

Many of these assessment measures are unfamiliar to engineering educators; however, they deserve consideration and trial. Issues that need to be addressed include determination and articulation of the attributes of these and other assessment methods. What information do they provide? How do their results correlate with traditional measures employed? Importantly, what are the time and costs associated with using these measures? And, finally, in what types of instructional settings are they appropriate?

Assessment is one aspect of the educational enterprise. Engineering educators can benefit by becoming aware of and applying the results of educational research, including assessment, to their own teaching. They can also contribute to teacher preparation and educational research by collaborating with faculty from education, science, and mathematics to bring meaningful examples and a sense of the end use of science and mathematics to curriculum development and research efforts.

E. Experiences for Elementary and Middle School Teachers

C. Roger Westgate, Reporter

Much of the discussion focussed on the teaching of science and mathematics. Few teachers in K–8

ERIC

seem to have engineering backgrounds; however, some of the suggestions to improve instruction would certainly help in engineering courses. Few seemed to believe that engineers needed to contribute much to teacher preparation; science and mathematics seem much more important.

The views of engineering by some members of the panel were not entirely positive. The topics discussed included the following:

1. *Topics Discussed*

a. Teaching of Mathematics

Demand for courses at the college and university level are high because mathematics is recognized as important. Adjunct and part-time faculty members have been employed to meet the needs, but quality is mixed. Students do not always take the courses needed. The traditional algebra I and II and geometry will evolve as a series of courses organized in modules. Recommendations include the development of model schools, the use of telecommunications to keep teachers in contact with resources, and the use of graphing calculators or computers.

The comment was made that engineering faculties seem to be more concerned with the mechanics of mathematics than with the understanding of the concepts of mathematics.

Another comment on mathematics concerned the difficulties in conducting dialogues with mathematicians. Most engineers could, on the basis of their standard chemistry and physics training, conduct meaningful discussions with scientists on a variety of research topics. However, mathematicians rarely conduct research on topics in courses that might be taken by engineers.

b. Changes in Teaching Methods

Faculty members tend to teach the way they were taught and to teach what they were taught. If they were exposed only to lecture courses, that is what they will do. Laboratories are not considered "essential" by some.

Needed changes include the introduction of "observation, discovery, and collaborative problem solving" on a variety of problems including interdisciplinary problems (for example, energy, environment). Middle school teachers would benefit from "real world problem" examples that might be suggested by scientists and engineers. It was thought that more effort should be placed into instilling curiosity and that some teachers had a phobia about science that stifled curiosity.

The comment was made that engineering faculties at some institutions have opposed the concept of collaborative working groups and favor individual effort.

It was suggested that undergraduates should be taught to make better use of resources outside the classroom.

c. Specialists at the Middle School Level

Mathematics courses for teacher preparation versus mathematics courses for physical science majors were discussed. It was believed that separate courses were needed. In contrast, most believed that special courses for teachers in the sciences were not needed.

The types of science that should be taught in the middle and elementary levels was discussed. Some favored depth in a few areas; others favored an interdisciplinary course rather than specific courses devoted to chemistry, botany, etc. Content seemed less important than ability to solve problems and to learn.

It was proposed that an interdisciplinary laboratory at the college level would be helpful, since teachers need to be able to teach a variety of topics and to deal with topics that cover more than one discipline.

d. Rewards for Teaching

Many believed that excellent teaching was not rewarded enough. Asked (by me) how one

measures excellent teaching, several answers were given, including assessments by students, chairs, etc. Still, many agreed that few good methods seemed available or easy to do.

e. Assessment

The issue of assessment was raised with respect to innovative courses. I asked how one can determine the success of a new course or a special section of a standard course. Replies included seeking out "College of Education Professionals." It did not appear that there was any readily available method for science and engineering faculty. All agreed that better assessments should be on the research agenda of NSF.

2. *Recommendations (related to engineers, among others)*

- Develop interdisciplinary laboratories
- Provide technology courses for liberal arts majors (who make up the majority of the teachers)
- Develop courses that encourage observation, discovery, and group problem solving that make learning an active process
- Develop better ways to assess courses and teaching
- Suggest real world examples of engineering that could be introduced in a middle school or elementary program.

There seems to be a major gap in vocabulary if not in concepts between those who teach and conduct research in science, engineering, and mathematics and those involved in teacher education. Research-oriented faculty members and deans simply do not have the time to digest the research produced by our education colleagues or to understand their ideas, good information on how to assess prospective improvements is lacking, and some of the better ideas on what ought to be done seem to be intuitive and untested. It would appear that many good ideas were the result of an inspired and dedicated person whose contributions did not live long after her or his participation.

F. Experiences for Secondary School Teachers

Karan Watson, Reporter

How can engineers and computer scientists help in the preparation of secondary educators in light of the fact that our courses are not commonly filled, even in a small percentage, by future secondary teachers? To begin, let me highlight a few of the key ideas about teaching, particularly good teaching, that were generated in the thematic group discussing the preparation of secondary educators.

- Students should have the opportunity to use what they are learning as they are learning it, or even more to the point, they should use what they are learning as a means of truly learning something.
- As a course is taught, all students should be viewed as future teachers, because whether it is formal or informal, all professionals will be in a position to teach.
- Good teaching is not dependent on general pedagogy alone. Attention should be placed on "Representational Repertoire," or content-specific pedagogy. It would be a relatively simple thing for instructors in the science, engineering, and mathematics fields to highlight briefly the pedagogy behind the subject, examples, or experiments that are being presented on a given day.
- The aspect of science, engineering, and mathematics that generally keeps us engaged in the field has a lot more to do with "doing science," not reading about it. We need to participate in training nonengineers to see that real science is about active engagement in exploration or problem solving, not passive submission to an enormous amount of facts.

Engineering and computer science educators must recognize that, even though engineering and computer science may not be common curriculum items in secondary schools, the science, mathematics, English, and communications skills that students obtain in precollege education have a direct effect on how good our college level students can be. Everyone knows that when you begin a process with high quality material you can be more efficient in the process of generating a final high quality product.

In addition, we engineers and computer scientists have an important stake in the preparation of secondary educators because a teacher's understanding of our professional fields has a lot to do with the kind of students that we will receive. This point was brought home to me in the description of a typical path that is taken by secondary educators. They attend school K–12, they attend college, they have a clinical experience in a school (i.e., student teaching), and then they go back into the schools for their professional life. In this process what have they seen and how can they identify with engineering and computer science? They have heard and seen the tough time college peers are having in the effort to keep up with the engineering curriculum. They perceive that only the brightest, or most disciplined, or most boring seem to stay in engineering and computer science curricula. They see media presentations of engineers as people who are totally absorbed by tasks and who are often dangerous in their capacity to ignore people and society. These images of engineering, which may cumulate to a positive or a negative representation, are not what engineers or computer scientists need depicted by the most influential academic influences on our precollege prospects.

To bring all of this together, we also discussed instructional technology as it relates to secondary teacher preparation. We at the college level must better utilize information technologies if we expect our future teachers to have a model on which to build. We looked at the influences and saw two prospective Venn diagrams illustrating the preparation of secondary science and math educators.

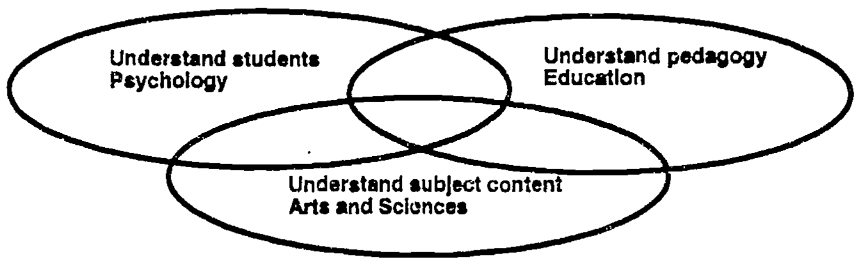

Figure 1. Presented by Glenda Lappan

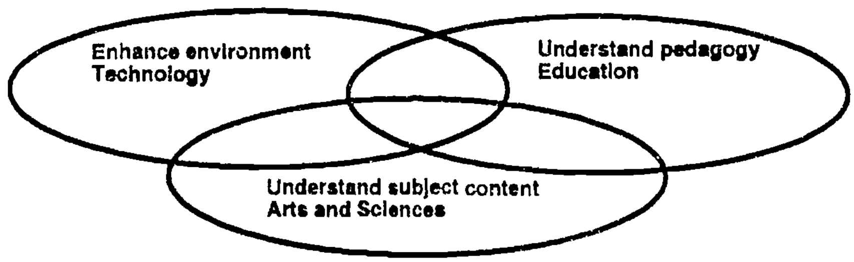

Figure 2. Presented by Beverly Park Woolf

In the first diagram, we the technologists must help in preparing teachers for careers in the intersection of the sets, as well as in the content areas. In the second diagram, we must not only participate in the intersection area, but also we should be actively involved in making sure that the technology to which we grow so accustomed is transferred to the teaching arena.

As a final comment, the prospect of computer science as one of the high school science choices was discussed in our thematic group. The point was made that this proposal concerns the science of computability, not just programming, literacy, or applications. In addition, I would add that secondary curricula should integrate engineering by showing that, whenever science and mathematics are used to solve a real world problem which is significant to society and people, we are utilizing engineering.

III. Comments and Recommendations

The conduct of the communities that provide the backdrop for our discussions—engineering, computer science, and teacher education—has been characterized by irresponsibility, an almost total lack of communication, and an inability or unwillingness to address a common problem that has reached crisis proportions: the decline in the math and science preparation of our high school and college populations.

1. We endorse ongoing efforts by the NSF to promote interaction between professional organizations and engineering, computer science, and teacher education faculties (including those whose focus is assessment and evaluation of performance) in order to improve engineering and computer science course development and teacher training.
2. We recommend that engineering, computer science, and education faculties should collaborate in the process of setting goals for research in education and for developing courses for engineering and computer science education.
3. We assert that interdisciplinary, project-based, freshman engineering courses are good for the general education of all students. Accordingly, an effort should be made to include these types of courses in the program of study for mathematics and science teachers.
4. Engineering and computer science faculties should work with professional organizations and teachers' groups including mathematics, science, and technical course teachers, to create new interdisciplinary approaches for precollege students.
5. NSF should support curriculum development and teacher training in computer science at the secondary level. In particular, we recommend that efforts be made to implement the Association for Computing Machinery Computer Science curriculum.
6. The problem of mathematics and science education is so acute and the need for resources to address this problem is so great, that some members of the panel suggested that the massive infusion of funding that the problem requires may have to come at the expense of funding for traditional research in science and engineering.
7. In all of the above endeavors, we recommend that participants explicitly seek ways to use student diversity as a resource, where diversity is seen as encompassing differences in preparation, goals and aspirations, learning styles, personal and group attributes, and history.

The Role of Geosciences Faculty in the Undergraduate Education of Science and Mathematics Teachers

John R. Carpenter, University of South Carolina, Chair

Panel Members: Bonnie J. Brunkhorst (California State College, San Bernardino), M. Darby Dyar (University of Oregon), George R. Jiracek (San Diego State University), R. Heather Macdonald (College of William and Mary), Maynard Miller (University of Idaho), Dorothy L. Stout (Cypress College), Kenneth L. Verosub (University of California, Davis)

I. Introduction

In accordance with the instructions given to all disciplinary panels, the Geosciences Panel met on Saturday, November 6, 1992. Each member of the geoscience disciplinary panel had been assigned to participate in a particular thematic panel on the previous day. Two members had been asked to make formal presentations to their assigned thematic panel. Six members had been assigned the role of reporting to the geosciences panel on those aspects from their thematic panel discussions that had particular relevance to the geosciences community.

It should be noted that the Geosciences Disciplinary Panel consisted of members of the geosciences (solid earth) community exclusively and was not representative of the more inclusive earth sciences community, of which the geosciences are but one discipline. There was no representation from the oceanography/marine science, meteorology/weather science, or astronomy/space science communities.

This report will consist of four components:

- Introduction
- Reports from Geoscience Representatives to Thematic Groups
- Presentations by Geoscience Representatives to Thematic Groups
- Recommendations to the Geosciences Community

II. Reports from Thematic Group Representatives

A. Instructional Innovation

M. Darby Dyar, Reporter

A variety of new and innovative approaches to science instruction exists that can foster tremendous improvements in learning of science mate-

rial (as abundantly demonstrated by research in the education communities). However, these are practiced predominantly by the science education community. Given the reality that the majority of future K–16 science educators receive their basic instruction in science from "basic scientists," it was recognized that a major barrier to the improvement of science instruction is the lack of communication between basic science research-oriented faculty and science education faculty. There is little (or negative) incentive to pursue such interactions. The two groups are in direct competition for funding from NSF and other organizations, causing mutual resentment, and different reward structures exist at the university level for the two groups (such that "excursions" outside one's area of supposed expertise are viewed as distractions from primary functions). Increasing enrollments coupled with staff cut-backs increase the imperative that discipline faculty bring in outside research funds to generate indirect cost revenue while simultaneously carrying heavier teaching loads. If the *status quo* continues, facilitation of learning at all levels (K–16) will continue to suffer, and we can look forward to increasingly mediocre instruction at all levels, declining enrollments of poorly prepared U.S.-educated students at the graduate level, and increased involvement of foreign students in U.S.-supported science research. As one workshop participant put it, we are "eating our own seed corn" for the future of science research in this country.

For the geoscience community, these problems are in some way mitigated by the traditions of our field. Earth and space science problems are frequently taught in a hands-on setting, such that even introductory classes have recitations, laboratories, and field trips which provide environments for collaborative and interactive learning. Geoscience problems are also especially well suited to open-ended and inquiry-based learning approaches because geological problems commonly lack unequivocal solutions. Geoscientists also lack, to a large degree, a responsibility to provide feeder courses for other disciplines (an obvious burden to introductory courses in biology, chemistry, and physics), freeing them from the constraints of coverage of specific material in introductory courses. Unfortunately, however, geoscience instruction frequently fails to take advantage of instructional innovation because of unique problems which compound those previously discussed.

During the 1980's, geoscience enrollments in upper-division courses for majors decreased as the fortunes of the petroleum industry declined. Many geoscience departments were forced to increase enrollments in their introductory and service courses to continue to justify their existences. But large classes are difficult to teach effectively because of the sheer numbers. As a result, the curriculum varies little from year to year (because there is no incentive to change). Most faculty find themselves teaching the introductory classes using exactly the same methods by which they themselves were instructed because they lack knowledge of the effectiveness of many curricular, instructional, and assessment innovations. In short, many of the service courses in geosciences have been shamelessly configured to require minimal time commitment from faculty and attract maximum enrollments.

As interest in environmental issues increased in the 1980's and 1990's, enrollments in upper division courses are again on the increase. However, even here, instructional innovation is difficult to implement with courses of 40–60 students. Few schools have the resources for every student to be able to look down a microscope or manipulate a computer screen at the same time as an instructor.

If the overall situation is to change, the geosciences must commit to changing the reward structure so as to facilitate instructional innovation. Unless such efforts are recognized to be valid *within our own evaluation criteria*, they are worthless. We should require or at least encourage advanced degree candidates in the sciences to participate in science education courses. NSF has an ever-increasing budget for educational improvement, but we must seek it out. In a recent round of proposals for undergraduate

curriculum and course development, only *FIVE* geoscience proposals were submitted.

Institutional change must include encouragement to individuals to begin to make individual change. But individual action is necessary if institutional change is to occur.

Individually, geoscientists can encourage change in many ways.

- Instructors of large classes should be aware of a large volume of research and ideas for working under large enrollment circumstances.
- Interaction, not competition, must be established between science educators and basic science researchers.
- Individuals can seek funding from NSF education programs and the many other private foundations who are concerned about these problems. (Their colleagues can support these efforts through co-authorship of such proposals and recognition of their successes.)
- Individuals can get involved with curriculum and textbook development in K–12 classes and establish partnerships between universities and local public schools.
- Individuals can sponsor summer workshops to bring K–12 teachers and science educators and researchers together.
- Finally, individuals working together can encourage professional societies to reward excellence in instructional innovation and to facilitate it through sponsorship of workshops and publication of special issues, even textbooks, to promote change and growth in geoscience curricula.

In short, the geoscience community must initiate change from within, on a widespread basis and a grassroots level if necessary, to take advantage of resources, research, and expertise which will enable us to facilitate learning in our classrooms. The longer we wait to begin this task, the farther behind we will fall as a discipline as a whole.

B. Valuing Diversity in the Educational Process

R. Heather Macdonald, Reporter

One of our primary goals as teachers should be to establish learning communities, or in the words of Craig Nelson, "Communities of discourse aimed at success in the field." Establishment of true learning communities, however, requires that issues of diversity be identified, addressed, and accommodated in the learning process. Important issues addressed by the panel included the following:

- Diversity should be viewed as a resource not as a problem. The learning community should be inclusive and should welcome and value contributions from all members.
- Diversity includes not only gender, ethnic, and racial diversity, it also means people with different learning and communication styles who have differences in experience, age, physical ability, and class background.
- Courses for prospective teachers should provide a variety of learning experiences and should be sensitive to issues of gender and race. Instructors need to include in their repertoire of teaching strategies not only lectures and laboratory work, but other teaching activities/learning opportunities such as demonstrations, writing assignments, oral presentations, individual work, small-group activities, and research projects. Such changes in teaching should result in more active involvement of students in learning and in establishment of communities of students who are "doing" geology (or engineering or biology).
- Changes in teaching strategies *must* be associated with changes in assessment strategies. Changes in the way we teach may also require changes in what we teach; depth may be increased and breadth decreased. Assessment strategies appropriate for different

learning styles need to be developed and implemented.

- Instructors should model a variety of teaching and assessment strategies for preservice teachers so that preservice teachers will be exposed to various learning strategies.
- Discipline faculty need also to form communities with other college or university instructors (discipline-based and professional education) who are interested in improving the quality of instruction. A network of practitioners would provide opportunities to share ideas, concerns, and problems.

Many of the issues raised during the theme session have been addressed by the geoscience community, but more must be done both to improve the quality of learning experiences of all students and to communicate problems and possible solutions to the entire geoscience community more effectively.

- Programs and organizations that deal with diversity issues are in place, such as the American Geological Institute's Minority Scholarship Program and the Association of Women Geoscientists. However, we need to do more to inform the larger geoscience community about effective mechanisms to increase the participation of groups that have been underrepresented. We need to learn from science educators more about appropriate teaching strategies for students with different learning styles.
- Many geoscience departments are already communities of learning where geology majors are actively involved in learning. Upper-level courses are relatively small, and students have many types of learning experiences, including field and laboratory work. They may also write papers, complete research projects, and give oral reports. Unfortunately, preservice teachers too often take only the large, entry-level courses designed for *all* nonmajors. Many of these courses do not include the diversity of learning experiences available in upper-level courses. We must change the ways that entry-level courses are taught.
- The geoscience community already has organizations of those interested in education including the National Association of Geology Teachers (NAGT), the National Earth Science Teachers Association (NESTA), and the recently formed Coalition for Earth Science Education. The *Journal of Geological Education* (*JGE*), published by NAGT, provides a vehicle to publish activities and assignments that work. However, we need to stimulate increased communication among geoscientists interested in these issues, and between them and science educators. We also need to make accessible for teachers at all levels (elementary to university), appropriate demonstrations and activities that are both good science and that enable all students to make a contribution. Discipline faculty need to become better informed about different assessment strategies. Articles written in *JGE* by geoscience educators would be useful. The value of good teaching needs to be recognized and acknowledged by the larger scientific community.
- Some geoscientists and geoscience organizations have recognized the importance of K–12 earth science education and are involved in various ways with inservice teachers and students. Partnering programs, such as those organized by the Geological Society of America and NESTA, provide valuable experiences for all involved. Programs similar to these need to be developed and implemented for preservice teachers as well.

C. Research on Learning and Teaching Science and Mathematics

George R. Jiracek, Reporter

Research has convincingly shown that emerging teaching strategies to improve science learning are exciting, even stunning. The main results are as follows:

- The standard lecture style of teaching is virtually ineffective.
- Most textbooks suffer from a linear, catalog-of-facts approach.
- Computer-based learning can play an effective role, but it is only a tool and cannot replace actual experimentation.

Probably the most shocking result is that, although good lecturing (the chalk-and-talk approach) can fire up students, very few students actually learn during lectures. Quantification of this result was presented by Priscilla Laws of Dickinson College. Test results show that lecturing improves test scores only about 10%, compared with testing before a physics course. Adding a laboratory helped, but the greatest improvement (over 60%) was attained by eliminating the lectures entirely. The new teaching approach is a workshop-based, small-group-discovery technique that uses computers for display and demonstrations by the students.

Elements of this hands-on approach are practiced in geology and geophysical field courses, and this undoubtedly explains the success of such experiences. However, the proven ineffectiveness of the traditional lecture is a shock to those few geoscience faculty who are aware of it. Worse yet, most geoscience faculty are not even aware of it. We must make even more of our faculty aware of the shortcomings of lecturing, but beyond that we must encourage them to act on this information and go beyond (or modify) the mind set that giving good lectures is the same as providing good instruction. University scientists must use the same scientific approach to teaching that they use in their other research efforts. We change and challenge our beliefs in our science but we do not do it in teaching and education. Most do not want to change and are threatened by it. Some believe that in lectures they have control, but in the newer techniques they would not.

It is clear that not only do the classrooms need changing, this is also true for most textbooks. Textbooks use an outmoded linear, catalog-of-facts approach which does not sufficiently develop the interrelation of topics.

Computer-based learning provides immediate feedback, reduces the tedium involved with excessive computation, and provides unmatched graphical visualization. However, even when it is highly interactive, there is no certainty that students are engaged at deep enough levels to ensure understanding. In fact, providing an environment without errors is actually counter to what research has shown to be most effective. Confronting and resolving problems are important learning experiences. Therefore, caution should be exercised when developing computer-based learning.

It appears that a major impact of the value of innovative, non-lecture-based teaching would be achieved if prominent (big name) researchers were to speak out on its benefits. Therefore, review articles in geoscience journals co-authored by established scientific researchers and science education researchers are strongly encouraged. This, however, will require higher levels of communication between scientists and educational researchers. Furthermore, this research must be of sufficiently high quality as to be believable. There are challenging, exciting opportunities for collaboration between scientific and educational researchers. It is particularly important that the research is responsive to actual classroom practice. Such action research will have major impact on curriculum development for both geoscience majors and prospective teachers.

Finally, reward systems, especially at universities, should recognize the importance of learning/teaching research as laudable activity by geoscience professors and graduate students.

D. Assessment and Evaluation as a Means to Enhance Learning

Bonnie J. Brunkhorst, Reporter

Pedagogy and assessment must be treated as interrelated components of the overall learning process. Inasmuch as good pedagogy has moved

beyond the primitive practice of teaching as telling, learning as listening, and memorizing facts, assessment must move beyond checking for retention of facts. It is generally agreed that science should be taught by inquiry, reflecting the very nature of science. Instruction in science should promote the contributions of science, scientists, and scientific research, but should always acknowledge the limitations of science.

Because assessment is a key variable in educational systems, expectations for higher levels of teaching and learning require higher levels of assessment than have traditionally been employed. Characteristics of higher levels of assessment to which we should strive include the following:

- Assessment must reflect the desired higher levels of learning.
- Assessment should provide students with the opportunity to show their success with a wide variety of learning accomplishments.
- Assessment should improve instruction.
- Assessment should also empower students to succeed, increasing the ways in which success is possible.

The implications of higher levels of assessment are enormous, not just for the precollege years, but also at the K-12/university interface. If higher order precollege learning is to occur, newer ways of teaching must be employed and newer ways of learning must be accommodated. Assessment for college entrance must then change so as to reflect this higher order precollege learning. Furthermore, college course assessment must also change to reflect the goals for improved complex learning. Complex learning requires complex assessment. Assessment should measure what science values, inform teaching, be meaningful to students' lives, take many forms, and fit many instructional situations. What is true for inquiry-based learning is also true for demonstrating that learning.

Given the changes necessary to improve the teaching and learning of science in all grades, K-16, and the new assessment needed in science instruction, the nature of geoscience makes the discipline a useful model and resource for good pedagogy and assessment.

The geosciences can make a unique contribution to

- The practice of good content-specific pedagogy and assessment when the instructional goals are to improve student learning for citizen literacy and for teachers of science, K-16.
- The context for coordinated/integrated science instruction and assessment.
- The experiences for using science to address complex issues, a major goal for new instruction and assessment.

Geoscience can provide the context for and demonstrate the complex nature of science. Problem solving in the geosciences requires the use of a multitude of data sources and inquiry approaches. Geoscience is a coordinated/integrated science. It uses the knowledge base from all other science disciplines to inform and develop its own discipline knowledge base and to address complex past, present, and future questions related to the physical world, including societal issues such as resource depletion and land use issues.

Geoscience inquiry can serve as a model for good generic science instruction. Geoscience is a tangible science which affects students in direct, observable ways. Geoscience topics lend themselves to direct inquiry-based learning. Geoscience also has an overarching organizational paradigm (plate tectonics) for its knowledge base, a useful organizer for coordinated science instruction and higher levels of assessment. Geoscience laboratory exercises lend themselves to complex situations and use of instructional technology for both instruction and assessment. Proce oriented instruction in geoscience deals naturally with evolving complex problems in science that lead easily to concomitant assessment modes.

Assessment should involve a variety of means to demonstrate complex learning. The nature of the geosciences and the characteristics

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of instructional activities inherent in the geosciences provide a rich resource for higher levels of science assessment models.

E. Experiences for Elementary and Middle School Teachers
John R. Carpenter, Reporter

The vast majority of teacher education programs focuses on the need to upgrade the content knowledge base, improve the pedagogical skills, and increase the sensitivity to learning style differences and changing mores related to assessment of inservice teachers. Too often we relegate to "later" the need to focus on programs that prepare prospective teachers. This is understandable in the light of large numbers of significantly underprepared practicing teachers of science and mathematics, and an inadequate cadre of teacher-educators in post-K–12 educational institutions. However, no matter how well we rationalize this practice, it still has the effect of treating only the "symptom" of the problem and not the root cause. Clearly sooner or later we must engage in a massive effort to revitalize and restructure our teacher preparation programs. The more this action is relegated to "later," the more difficult, expensive, and time-consuming the task will be.

Among the issues discussed in the thematic panel, the following topics were of particular interest to the geoscience community.

Characteristics of Appropriate Course Experiences

It was agreed that science and mathematics courses for prospective teachers should be designed to address the special needs of prospective teachers. There was also general agreement that characteristics of appropriate course experiences should include the following:

- Emphasize discovery and inquiry.
- Emphasize improving and utilizing observational and data-gathering skills, the nature of science, and the scientific method.
- Be transdisciplinary, showing the interconnectedness between science and other disciplines (mathematics, social studies, etc.).
- Model appropriate instructional and assessment strategies.
- Emphasize problem solving and the improvement of higher-order thinking skills.
- Involve participation in laboratory or field activities with easily obtainable materials;
- Introduce students to current national curricula reform initiatives and recent research findings involving pedagogy and assessment.

Barriers to Implementation of More Effective Courses

While the above characteristics were agreed upon early in our discussions, it was clear that courses with those characteristics are rare in teacher preparation programs. Barriers to the implementation of more effective courses (and programs) include lack of consensus on questions concerning the learning environment in which these courses should be taught:

- Should there be separate content emphasis courses for prospective teachers or should they be required to take science and mathematics courses designed to satisfy a general education or core curriculum requirement?
- Should content and methods courses be taught in separate courses or as an integrated experience?

Too often, curricular, instructional, and assessment issues that must be addressed in the development of appropriate courses for preservice teachers are not even considered. In many professional education courses, there is too much emphasis on methods, to the virtual exclusion of content with any thread of continuity. In many discipline courses, there is too much emphasis on content, to the virtual exclusion of appropriate science teaching methods.

Reasons for these deficiencies revolve around inadequate staffing and funding of teacher-

preparation programs at the college/university level:

- Too often, professional education faculty have too little content knowledge and discipline faculty have too little knowledge of appropriate instructional and assessment strategies.
- In the disciplines, there is a need to "service" large numbers of nonmajors in general education or core curriculum courses. Too often, these are the only "introductory" science courses available to preservice teachers. Too often, these courses are taught by unenthusiastic or inexperienced instructors, utilizing antiquated instructional strategies, an encyclopedic approach to content, inappropriate assessment strategies, and little or no emphasis on the relevance of science and scientific research or implications of individuals, society, or the environment.
- There is a lack of an appropriate reward system to encourage underprepared teacher–educators (professional education and discipline) to become better prepared or to work cooperatively with one another.
- There is a lack of respect between discipline faculty and professional education faculty and a lack of respect on the part of many discipline faculty for their peers engaged in educational research.

Recommendations for implementing both short-term and long-term change in all discipline areas have implications for the geoscience community:

- Design new courses. In the best of all possible worlds, there would be specially designed, integrated content/methods courses, not "watered down" but emphasizing appropriate content, modeling appropriate instruction, and employing appropriate, authentic assessment. These courses would be team taught (by discipline and professional education faculty) or taught by faculty knowledgeable in both areas.
- If the above suggestion cannot be implemented, develop special laboratory or recitation sections in general education or core curriculum science and mathematics courses for prospective teachers that include the above criteria.
- Begin to address a reward system that too often punishes a faculty member for devoting research time to teaching and that discourages discipline and professional education faculty interaction.
- Encourage NSF and other funding agencies to fund larger, more systemic research and development projects that address shortcomings of teacher–educators and prospective teachers with respect to curricula, instruction and assessment and that implement faculty development workshops to fill in the knowledge and skills gaps in those faculty who wish to, or are assigned to, work with prospective teachers. These projects should be research based, and funding should be contingent upon the development and implementation of a comprehensive project assessment plan.

F. Experiences for Secondary School Teachers
Kenneth L. Verosub, Reporter

Perhaps the most important theme to emerge from the discussion of the needs of prospective secondary school teachers dealt with characteristics of appropriate science learning experiences for secondary school teachers. These characteristics include, but are not limited to, the following:

- Courses should be participatory learning experiences, including a variety of inquiry and problem-solving strategies.
- Courses should provide a coherent framework for understanding a discipline.
- Courses should provide a vision of the discipline that enables a teacher to decide what to teach and how to teach it.
- Courses should make appropriate use of instructional technology.

- Courses should be the basis for life-long learning.

The nature of the geosciences and characteristics of good geoscience instruction are such that the geosciences can serve as a model for other science experiences. Some of the characteristics of the geosciences and the appropriate instruction thereof, include the following:

- The geosciences are among the most tangible of the sciences, affecting students in many direct, observable ways.
- The geosciences draw on all scientific disciplines and provide a unique integrative context in which the other disciplines can be taught.
- The geosciences are now and will continue to be a pivotal discipline of many primary science problems facing contemporary society.
- The plate tectonics paradigm provides an overall framework for all of the geosciences.
- The process-oriented nature of geoscience instruction creates a mechanism for dealing with new or evolving problems.
- Many geoscience topics lend themselves to direct inquiry-based learning using simple models and easily available materials.
- Geoscience field experiences provide students with the opportunity to solve real-life problems.
- Geoscience laboratory exercises can be extended to complex situations through instructional technology.

III. Presentations by Geoscience Representatives to Thematic Groups

Two members of the Geoscience Disciplinary Panel were asked to make formal presentations to their assigned thematic panels. Dorothy L. Stout presented the paper, "Science Exhibitions Promote College and Community Interaction," to the thematic panel on Instructional Innovation. The paper originally appeared in the *Journal of Geologic Education* and has been reprinted with permission in this issue, page 58. R. Heather Macdonald presented the paper, "Various Teaching Strategies in Entry-Level Geology Courses: Opportunities for Students with Different Backgrounds and Learning Styles," which appears in the chapter, Valuing Diversity in the Educational Process (in this issue, page 81).

IV. Recommendations to the Geosciences Community

After extended discussion on reports from the thematic panels, the geoscience panel urges that the following statement be conveyed to faculty and administrators within the geosciences and other science disciplines:

Because geoscience draws on all science disciplines, it can provide a unique interactive context in which principles from other disciplines can be applied. It is a pivotal discipline for resolving critical environmental and economic issues.

The panel then identified four major recommendations that it believed should be conveyed to the geoscience community.

1. We need to communicate to geoscience faculty the need for and value of incorporating the unique aspects of the nature of the geosciences. We also need to stress to them the value of using a variety of creative instructional and assessment techniques and methods when establishing the learning environment for all students. These should include, but not be limited to, the following:

    a. fostering active student inquiry through participatory strategies;
    b. placing geology in the context of earth systems;
    c. demonstrating the relationship between the geosciences and important public issues such as the economy, technology, and the environment; and
    d. stressing to students the knowledge and processes that scientists value.

There is a desperate need for faculty development programs for both college/university and K–12 faculty. Coordination among college/university faculty and between college/university and K–12 faculty must be increased. Finally, we need to encourage the development of landmark papers on geoscience education.

2. For geoscience faculty, research and practice in geoscience education should be recognized and rewarded. Faculty and administrators need to be aware that significant contributions in this area will require what follows:

   a. additional education and practice;
   b. collaboration with science educators as part of their necessary expertise; and
   c. inclusion of K–12 teachers as an integral part of the geoscience community.

   There are examples within the geoscience community of individuals and institutions who are achieving these goals already.

3. We need to encourage geoscience faculty to pursue funding from NSF and other agencies for teacher preparation and enhancement, equipment, and curriculum and professional development support.

4. We recommend that NSF develop new incentives to encourage geoscience research faculty to interact with science educators in joint efforts to improve geoscience education. These incentives could include encouraging professional societies to participate in these endeavors by

   a. creating awards and recognition mechanisms;
   b. publishing textbooks developed in conjunction with science educators; and
   c. funding/facilitating K–16 curriculum development.

   Another incentive could create mechanisms and incentives to assist proven science researchers who might wish to pursue career redevelopment in science education through

   a. NSF-funded faculty leave programs to retrain basic scientists as science educators; and
   b. a prestigious, Presidential-Young-Investigator-like program, based on research expertise, to give our best and brightest basic scientists exposure to science education programs and methods.

The Role of Interdisciplinary Faculty in the Undergraduate Education of Science and Mathematics Teachers

Daniel Fallon, Texas A&M University, Chair

Panel Members: Rick Billstein (University of Montana), Angelo Collins (Florida State University), Joan Ferrini-Mundy (University of New Hampshire), Jim Henkelman (University of Maryland at College Park), Bess C. Howard (University of Maryland at College Park), Maxie Kohler (The University of Alabama at Birmingham), Steve P. Landry (The University of Southwestern Louisiana), Francis Lutz (Worcester Polytechnic Institute), Richard L. Magin (University of Illinois), David W. Mogk (Montana State University), William Sayle II (Georgia Institute of Technology)

I. *Report of the Panel*

A. Some Conventions

Let us begin by stating a convention we will follow throughout our discussion. Whenever we use the term "science," we ask you to read "science, mathematics, and engineering." Similarly, when we use the term "scientist," we generally mean "scientist, mathematician, or engineer." The convention does require some intelligent interpolating from time to time. If the discussion pertains to laboratory bench work, for example, it is probably less directly applicable to mathematicians. We have written this contribution, however, for broad accessibility, hoping to reach the entire audience embraced by NSF in its concern for the improvement of science teaching. Finally, whenever we use the term "university," we mean for it to apply to any academic setting, whether it be called a college, institute, or something else.

B. Introduction

We found that our task was qualitatively different from the task of each of the disciplinary panels. For a given disciplinary panel, the task is conceptually straightforward: bring the findings of the six thematic panels to bear on a recognized discipline. Thus, physicists, for example, gathered on a panel, treat issues associated with preparing teachers of physics. We, on the other hand, represented many different disciplines. Were we to treat issues associated with preparing teachers of interdisciplinary science? Indeed, consideration of this question convinced us that it was an important matter, more important than most observers might at first imagine. We did, in fact, address it, and include two special presenta-

tions on models of science that are interdisciplinary.

We concluded, however, that to organize our work around "interdisciplinary science" would not be very helpful to the aims of scientists, teachers, or NSF. Most scientists work within the framework of productive and secure relationships developed by the traditions of a recognized discipline. We believe that this reality should be our starting point. Therefore, we sought to define cross-cutting subjects that apply to scientists in their own disciplines, but that are of universal value when applied across all science disciplines.

Our approach is most clearly seen by the first question we used to focus our work: What activities or principles will be helpful to any college faculty member teaching science in courses taken by prospective teachers? A second question helped us to refine the answers we accrued to the first: How can scientists be sensitive to the interdisciplinary science needs of their students, while at the same time teaching their own disciplines with integrity? Considerable discussion led us to consider about a dozen general subjects, which we eventually succeeded in reducing to just four. These constitute the most efficient replies to our two questions.

C. Four Discussion Subjects

1. *Collaborative Initiatives*

Whenever conferences are convened to consider the problems associated with preparing prospective teachers of science, one pressing need is inevitably and quickly identified. It is for information: relevant data, research findings, and persuasive theoretical formulations. At the same time, as we all know, there is a long-standing tradition of collaboration in science. The collaborative tradition could be fruitfully applied to the newly emerging problem area of science teaching.

The simplest collaborative to establish on a campus would be among scientists across disciplines. We also believe that such a collaborative is perhaps the most needed and could be the most effective at this stage of treatment of the problem of science teaching. The purpose of the collaborative would be to examine the teaching of science. Although the domain could include all undergraduate science instruction, it would be most helpful if the focus could be on that subset of students who are contemplating careers as science teachers in the elementary and secondary schools. The value of such a focus is that it must stress the analogies and strategies by which science is effectively taught. It is by considering these devices for teaching science that we find that we are, in fact, considering the meaning of science.

A second collaborative would be among scientists and appropriate faculty from within the community of professional educators on campus. This kind of collaborative is often difficult to establish because there are deceptive disciplinary barriers to communication on both sides. Scientists sometimes distrust or devalue the research basis for pedagogy. Conversely, educators sometimes do not perceive the essential bases for knowledge within particular scientific disciplines. These barriers can be overcome by rigorous attention to real problems. A useful device is to organize a seminar in which two broadly accessible important papers will be discussed, one selected by a scientist and the other by an educator. When the collaborative among scientists and educators is established, it can become the locus for the dissemination of specific research findings from pedagogy as they relate to science and to the transfer of teaching technologies among the disciplines.

A third collaborative would be among scientists in different disciplines related through treatment of broad common problems. This is a common mode of operation with much fertile precedent, as, for example, in environmental science. It is through this kind of collaborative that we best understand science as "interdisciplinary." Furthermore, interdisciplinary science collaboratives of this kind provide the best strategy for meeting the increasingly urgent need to prepare teachers of "integrative general sci-

ence." General science teachers, formerly limited primarily to elementary schools, are now increasingly being sought by school boards for middle school and secondary school teaching. Because science teaching at universities is done virtually exclusively within disciplinary departments, the preparation of prospective general science teachers is a major problem that needs to be addressed very soon. Doing so through an interdisciplinary science collaborative can be readily implemented and maintains the integrity of the scientist. We provide in Section II two examples, prepared by members of our panel: environmental geology and bioengineering.

We have proposed three kinds of collaborative initiative that will serve the purpose of improving the education of prospective teachers of science. The first is among scientists to examine the nature of teaching science. The second is among scientists and educators to apply findings from pedagogical research to the teaching of science. The third is among scientists from different disciplines working on a common broad problem. Conceptually, such collaboratives are relatively easy to implement. We are also convinced that they are among the most productive ways that scientists can treat the important issues associated with science teaching.

We do not believe, however, that it will be easy to establish effective collaborations. Those who wish to succeed cannot afford to be glib. The allocation of time and effort on the part of productive scientists must be faced directly. New ideas and methods will be needed, such as the seminar we suggest for the collaborative between scientists and educators. First and foremost, no collaborative can be expected to succeed without the participation of at least some of the most distinguished scientists on campus. This consideration leads naturally to the second subject we address.

2. *The University Reward System*

A theme repeated throughout this volume is that the prevailing academic culture does not sufficiently or properly reward those who are devoted to the improvement of teaching. We concur. The problem is not that we properly value the quality of mind that accomplishes significant new science. We have the methods to determine which scientists meet the research criteria we set, and we have confidence in our judgements based upon the methods. The problem is partially in assigning a higher value to the quality of mind that advances effective teaching. More important, however, is developing the methods we need to determine which scientists meet the teaching criteria we set, and building confidence in our judgements. This is, nonetheless, a task that can readily be solved, if the will can be found to pursue solutions.

The evaluation of teaching in universities can and should be promoted in a manner parallel to the evaluation of research. The focus ought to be upon the quality of mind brought to the enterprise of teaching. There are many data that can be considered analogs to publication, especially if they are subjected to rigorous peer review, even if only among departmental colleagues. Among these are course syllabi; selection of learning materials, including texts; construction of examinations; development of laboratory exercises; and the successful introduction of wholly new courses. Similarly, application for and receipt of nationally competitive grant awards for the improvement of teaching can and should be considered as positive evidence resulting in faculty advancement.

As a practical matter, efforts to increase the value universities place on teaching are likely to succeed in direct proportion to their acknowledgment of the value of the prevailing reward structure. A simple method to harness this valuable intellectual energy is to exploit a well-known feature of human development. As adults mature within the academy, their motives change. Generally, the motives that most drive faculty in their thirties are different than the motives important to faculty in their fifties. Often, older faculty place a higher priority on building institutions than on building their

personal careers. This is at least in part because the most successful among them have already achieved extraordinary acclaim through their science and have taken their measure of personal satisfaction from it. They are open to broader and more universal challenges. Therefore, it is usually relatively easy to recruit senior distinguished scientists to the cause of the advancement of science teaching.

The participation of distinguished and successful scientists in the improvement of science teaching is essential if reward structures within the academy are to be made more sensitive to genuine contributions of quality in science teaching. For example, there are usually troublesome disincentives relating to allocation of time and effort in promoting effective techniques such as team teaching and the formation of collaboratives aimed at the improvement of teaching. These can be more readily ameliorated through the effective advocacy and participation of distinguished senior scientists.

3. *Human Diversity*

Diversity is an important feature of our biological environment and an essential component of molecular, cellular, and organismic development. The value of biological diversity serves as a productive metaphor for the cultural diversity that comprises the American citizenry and is represented in its classrooms. Like its biological analog, human diversity is a resource that can and should be developed. Recognition of this principle can do much for the advancement of scientific literacy. We cannot hope to sustain a political culture supportive of science unless the citizens of the state understand science sufficiently well to be able to value it properly.

One aim of science education ought to be inclusiveness, connecting fundamentally with all of the cultures represented in today's American classroom. Conscientious efforts to devise teaching strategies which reach out to students of different cultural backgrounds also improves the scientist's own understanding of science. It holds the promise of creative new assaults to unlock the secrets of nature and logic. Sensitivity by the science teacher to the different cultures present in the classroom leads directly to an appreciation of diverse strategies and to the development of adaptive scientific habits of mind. It can and should also lead to multiple means of assessing student mastery of content.

4. *The Academic Major*

Here is a simple rhetorical question. If a student graduates today from your university with a bachelor's degree, holding a major in chemistry (you may substitute any science discipline here), does that student know "chemistry" sufficiently well to be able to teach it in an American high school? We believe that the thoughtful and well-informed answer to this question is simply no. Furthermore, the primary reason for a negative answer is that the academic major program in today's university is not designed to produce a coherent conceptual understanding of the discipline.

As scientists in the academy, one measure of our lack of quality attention to teaching is in our neglect of the very curricula that define our disciplines for undergraduates. For the most part, the academic major program in the sciences consists of a collection of between 8 and 14 courses that have, at best, tenuous relationships with one another. There are hardly any major programs with serious integrative senior experiences designed to bring the discipline together as a coherent whole. Yet it is from this largely hodgepodge basis that we provide the "subject matter" for prospective teachers who expect to spend a lifetime teaching science to innocent learners. These college graduates must do what they can to make sense of what we teach them. Since we provide them with so little guidance, it should be no surprise that idiosyncratic and often false conceptions abound in the public schools.

There is an urgent need for scientists in the academy to examine the academic major pro-

grams in the sciences and to rebuild them. A major program must deliver essential principles, facts, and skills. Most important, however, it needs to convey a sense of the meaning of the discipline, a visionary perspective that will promote lifelong inquiry. The prospective teacher deserves to win a deep comprehension of the purpose of science in general and the value of the discipline in promoting understanding of the world around us. This is most likely to occur if scientists deliberately teach their students about the coherence and meaning of their disciplines.

D. Summary

We set out to identify subjects that would be universally valuable to scientists, irrespective of their own discipline. Our intent was to respect the fundamental integrity of disciplinary science while at the same time addressing the functional need of many students for general understanding of science. In this essay we have treated the four subjects we found to be the most efficient for scientists to explore. These are collaborative initiatives; the academic reward structure; human diversity; and the academic major.

Where we were able, we have proposed quite specific courses of action. These include an academic seminar as a means of promoting collaboration between scientists and professional educators and the recruitment of distinguished senior scientists to campus-based initiatives aimed at advancing the teaching of science. Elsewhere, we have pointed the way toward consideration of subjects especially powerful in the improvement of the practice and teaching of science. Thus, we suggest that conscientious attention to the human diversity in our classrooms when we teach will improve not only our teaching of science, but our knowledge of what we teach. Finally, we urge that serious efforts be undertaken nationwide to rebuild the academic major program in science. What is needed is a curriculum that imparts the coherence of the discipline and the visionary perspective that makes lifelong inquiry a natural habit.

II. Examples of Interdisciplinary Science Collaboratives

A. Environmental Geology as a Vehicle for Multidisciplinary Science Teaching
David W. Mogk

Science in its many forms, and its attendant technologies, pervades the workings of society and the conduct of our lives. In recognition of the ubiquitous application of scientific principles to the world around us, it seems reasonable to teach these principles, and to demonstrate their applications, in a variety of venues. For example, concepts of energy and mass, their distribution and transport, are not restricted to any particular discipline of the sciences. In addition, the applications of these concepts affect a broad spectrum of human activities (e.g., public health and safety, resource allocation and utilization, transportation, and communications). A multidisciplinary approach to teaching basic scientific concepts serves to make connections between the sciences, our society, and our personal lives.

The *Project 2061 Science for All Americans* (AAAS, 1989) report provides a blueprint for scientific literacy. One of the central recommendations is that science be taught in an historical perspective. I would venture to add that science also be taught in geographic, social, economic, and political contexts as well.

A component of science education lies in each of the following questions:

- What physiographic and climatologic factors controlled settlement of the lands west of the 98th meridian? How did these factors conspire with human activity to produce the Dust Bowl of the 1930's?
- How do we evaluate reports that people of color, or from low-income communities, have been affected to a greater extent by exposure to hazardous or toxic materials?
- What are the economic costs and benefits of development of a mine (or other large resource-based project)? Are there alternatives

to development of the mine at this particular site? What is the global distribution and availability of this commodity? Are there alternatives to using this commodity?

- To what extent has America's need for the metals chromium and platinum, produced in South Africa, dictated our policy regarding apartheid?

An informed citizenry is required for the successful operation of our democratic government, and an informed citizenry must be scientifically literate. There is a measure of scientific literacy required for members of our society to read the headlines in the newspaper in a meaningful way, to step into the voting booth and make well-considered judgements, to make informed decisions as consumers, and generally to act as responsible citizens. Connections must be made between the private and public institutions of our society and the conduct and products of scientific investigations. It is incumbent upon working scientists to demonstrate that "science" does not consist of a static body of knowledge practiced solely by an inner circle of cloistered initiates. We must seek ways to demonstrate the relevance, utility, and implications of our work to problems that face society-at-large.

Topical issues in environmental studies offer a convenient vehicle to introduce scientific principles in the context of societal problems. These issues typically do not have a "right" answer, and are the result of values or priorities in conflict. One need only read the daily newspaper to find a rich selection of topics to cover. My emphasis is on resource and environmental geology. In the course of a semester, I can expect to extract class material on contemporary problems from the local newspaper on topics such as zoning versus development and the impact on land use in our county, permitting of mines and requests for variances from water quality standards, the question of hazardous waste burning in a local cement kiln, and the debate surrounding the release of water from Montana's dams to help save the now-endangered salmon on the Columbia River. On a national and international scale there is similarly a variety of subjects from which to choose: global warming, deforestation, global soil loss, drought, etc. All of these topics can be used directly to form the basis of a study unit that allows the introduction of the underlying scientific principles and also demonstrates the relevance of science to our personal and communal lives.

The benefits of using topical issues as a point of departure for introduction of scientific principles are (a) the materials are widely available, and are not costly; (b) teachers at all levels can readily make the connection between the perceived problem, and describe and interpret the causes and effects based on scientific principles; and (c) these issues are controversial and typically arouse the interest (and passion) of students. This results in a greater level of class participation, helps students to focus with clarity on the reasons for their own solutions to the problems, and allows students with diverse experiences to engage an open and informed discussion of the topic. For example, I typically show an advertisement published by a local mining company that shows a picture of an "American Dream" home; the caption reads "Life in a 120 Ton Mineral Deposit" and the information presented shows the bulk raw materials that were used to construct this house. Students react to this advertisement with increasing skepticism as they think about the implications: Is this a value system that I agree with, are there alternatives to these materials, is this really an "average" house, what if everyone built a house like this, behind those 500 pounds of copper how big of a hole was produced (1 ounce of copper is typically recovered in a cubic yard of rock using today's mining technology), and how much acid drainage and release of heavy metals occurred to extract the copper? Exercises such as this help introduce concepts of ore-forming processes, global distribution of resources, technologies required to develop resources, and environmental protection procedures; they also directly establish the connection between our personal lives (e.g., our consuming habits, the protection of our health and safety) and underlying scientific principles.

Environmental studies is just one of many possible topics that could be used to engage multidisciplinary instruction. Bioengineering (e.g., Magin, Section B below) has been proposed as one subject that could accommodate this approach. Biochemistry (what is the biochemistry of "the pill" or the RU-486 drug), genetics (fetal tissue research), and engineering in general (we may have the technology to engage in a given project, but what are the human or social consequences) are all fields of scholarship that can readily be integrated into interdisciplinary study programs.

One of the most effective ways that science faculty can help prepare future science teachers for their careers in the classroom is to help them see scientific principles in everyday events. This helps to make the information more accessible to the students because of their relative familiarity with the subject. It also helps the students to explore the situation by asking directed questions about the circumstances. It allows for diversity of opinion and multiple independent ways of exploring the situation. The scientific information is necessarily introduced as being meaningful and relevant, and connections are made with the effects to society (economic, political, social, etc.).

Reference

AAAS. 1989. *Project 2061 Science for All Americans* (American Association for the Advancement of Science, Washington, DC), p. 217.

B. Bioengineering as a Vehicle for Multidisciplinary Science Teaching

Richard L. Magin

The conventional training of future science teachers is under scrutiny as methods are sought to improve the effectiveness of science and mathematics education in American schools. Traditional teacher education programs place constraints on the time devoted to individual scientific disciplines. In addition, inadequate student preparation often limits each subject to a relatively superficial treatment. A new approach with the potential to overcome some of these problems is to restructure science education as an interdisciplinary program (e.g., in environmental science or bioengineering). An interdisciplinary program has the advantage of connecting distinct scientific subjects in a context that is readily grasped by student and teacher. It naturally leads to an inquiry approach to learning and is easily extended to issues of ethics, sociology, and governmental policy. Interdisciplinary methods are sometimes criticized as leading to a superficial treatment of a topic, but this need not be the case. In fact, with proper supervision, an interdisciplinary approach can be used to great advantage by a teacher because it enables more students with diverse experiences, backgrounds, and academic skills to get involved.

A variety of new classroom materials have been developed around specific environmental themes such as pollution control, recycling, and global warming. While these projects serve as a useful starting point, they do not provide the analytical tools of modeling and simulation that are needed to evaluate alternative designs. We believe that, by our considering an "engineering approach" to interdisciplinary topics, a wider range of scientific subjects can be introduced and that technological, societal, and environmental trade-offs can be introduced naturally into the curriculum. Just as environmental science considers the earth as a whole as the focus of study (e.g., see Mogk, Section A above), bioengineering considers the human body and its component parts as the primary topic of study. The analysis can proceed outward by considering the interaction of the senses with the environment (temperature, weightlessness, radiation) or inward with the study of events that occur within the body (brain or heart electrical activity, digestion, muscle function). The connection between the inner and outer functions is often under the control of the individual so concepts of choice and responsibility are naturally introduced.

In order to illustrate this approach, we have selected several examples taken from the field of

bioengineering. It is believed that these ideas could be used as a starting point for the development of new interdisciplinary curricula materials that could supplement the traditional training of science teachers. The use of such materials would expand the options available to instructors and present new ways to engage reluctant science students in the process of learning.

Example 1. Physiological Modeling

Physiology is a dynamic science most clearly described in the laboratory environment, but too often students enter into the laboratory without a comprehensive view of why they are there and the direction they "should" follow. Presenting students with animated, graphical demonstrations of how the data are collected will strengthen the connection between laboratory experiments and classroom experiences. Computer-based software can be developed to provide an interactive/controllable environment to allow students to experience realistic simulations of experiments in physiology. Animations combined with live and still video images, illustrating the molecular basis of many fundamental physiological processes, can be used to support laboratory exercises. Specific examples of laboratory situations in which simulations can be used include the solution of the Hodgkin-Huxley model of the membrane of an excitable cell, the behavior of single ion channels using patch clamp techniques, and the effects of drugs. In the case of drug effects, simple compartmental pharmacokinetic models can be developed that describe the uptake, organ distribution, and elimination of chemical substances such as aspirin, caffeine, ethanol, and cocaine. The focus of such models would be on the dynamic processes that occur in the body following administration of a drug. The goal of these learning activities is to demonstrate how scientists predict and model a wide range of physiological processes.

Example 2. Medical Imaging

Many relatively new medical imaging methods (magnetic resonance imaging [MRI], ultrasound, computerized axial tomography [CAT], gamma-ray scintigraphy) have been developed for obtaining images from within the body. These noninvasive techniques use acoustic, electromagnetic, and ionizing energies to interrogate the structure and function of specific regions of the body. Each form of energy interacts with the body in a unique manner determined by anatomical structure, chemical composition, and frequency.

Medical imaging is well suited for computer display and modeling. A description of different medical imaging techniques (CAT, MRI, positron emission tomography [PET], ultrasound) can be provided for the student using HyperCard stacks, which allow student-directed examination of the information. For each technique, information could be provided which includes the form of energy employed, a brief description of principles of operation, the area of the body for which it is typically used and why, resolution, safety considerations, typical cost of the instrument and examination, and the advantages/disadvantages of each technique compared with other procedures.

In addition, computer animation could be used to illustrate the basic principles underlying each modality. Actual images obtained from animals or patients for each modality could be presented. Anatomical regions appropriate to each modality could be chosen and, for regions where several modalities can be used (for example, the liver or kidney), both types of image would be presented and may be compared side by side to illustrate the differences (for example, CAT and ultrasound). Examples of normal and pathological tissues would be employed as well as some images acquired with the use of contrast agents which selectively alter the signals obtained from different tissue regions. A key

feature of this approach is that it will enable the student to examine selected anatomical regions using different imaging methods to gain an appreciation of the capabilities and limitations of each modality.

Example 3. Cellular Bioengineering

Cellular bioengineering deals with the physical or chemical modification of the basic functions of human blood and tissue cells (adhesion, migration, proliferation, secretion, and protein uptake and transport). These functions are fundamental to an extremely wide spectrum of physiological and pathological processes, and much of modern health care biotechnology is directed toward pharmacological or genetic modulation of them. Over the past decade substantial progress has been made in developing useful mathematical models for important aspects of cell behavioral functions. Particular examples of cell behavior (cell proliferation cycle kinetics, virus binding to and infection of cells, and models for protein uptake by cells) could be examined through the following computer simulations. Such simulations would enable students to visualize the effect of various parameters on the complex mathematical models without having to solve the actual equations.

Example 4. Radiation Safety and Biological Effects

Today's engineer, scientist, and citizen must be cognizant of safety issues associated with the potentially harmful effects of the various forms of electromagnetic energy and radioactive particles encountered in our environment (e.g., ionizing radiation, microwaves, and 60-Hz fields). Through the use of computer simulations, we can acquaint students with the possible harmful effects of ionizing and nonionizing radiations and address the role of engineers and citizens in society with respect to the proliferation of technologies that benefit mankind, but may also produce harmful effects.

As an example of how these factors could be studied in a computer simulation, consider a situation where a walking man or woman is allowed to explore a neighborhood through a graphical display. The figure could be observed to pass near a variety of different sources of electric and magnetic fields (60-Hz power lines, high-voltage transmission lines, radio and television transmitting towers, and microwave communications systems) as it moves around a town. The figure would also be allowed to select appropriate field measurement instruments to quantify his experiences. Throughout the walk, which will be controlled by the student, the intensity and frequency of the electric and magnetic fields will be measured. As the individual approaches each of the sources, the biological effects known to be produced by such fields would be visually illustrated. In addition, at any time during the tour, the student would be able to call up for display scientific data that support the biological effects observed. In this manner the student would obtain an understanding of the interaction of these fields with human beings and gain an appreciation of their distribution in our society. A similar walking tour to that described above could be designed for a neighborhood that includes different sources of ionizing radiation (nuclear power station, low-level radiation waste storage site, nuclear weapons facility).

The analysis of a specific bioengineering activity (action of a drug on the body, design of a wheelchair or prosthetic device, or the detection of disease using modern medical imaging techniques) can proceed at many levels with a variety of models, mathematics and physical concepts included. Through this approach the teacher is able to introduce the entire range of scientific disciplines to address each specific topic. This feature of interdisciplinary problems is familiar to engineers, materials scientists, and environmental experts. We believe that this method of examining all aspects of a scientific or technological problem can also be used to an advantage in the training of teachers.

III. *Reports from Thematic Group Representatives*

A. Instructional Innovation

Steve P. Landry, Reporter

Abstract: One core theme was getting students to participate actively and challenge their existing models through guided inquiry. Tools reviewed are hands on, interactive, and relatively inexpensive; allow direct observation of the phenomenon; and provide immediate feedback through alternative representations.

In general, I would say that the context for this day of activity and speculation focused on exploring ways to shift from or change the prevailing educational paradigm, that is, to move from the "teaching is telling and learning is listening" paradigm to something more effective. Six distinct segments explored methods for changing the current paradigm or complementing it to improve it. Four of the segments were highly participatory and engaged the panelists in the learning activity. Two of the segments explored *"collaborative learning."*

In one of the segments, facilitated by Gillian M. Puttick (this volume, page 49), the primary experience was problem solving that combined timed individual and dyadic sessions. Within the dyad, participants alternated talking about their insights and observable barriers in the problem at hand as well as their feelings about their current experience. In the other collaborative learning segment, facilitated by Sarah B. Berenson (this volume, page 61), participants formed into groups of four or five to extend jointly their working knowledge of the phenomenon that produces the phases of the moon. In this segment, which can be characterized as "guided inquiry," participants were provided manipulative (model) components that facilitated the construction of models with which to explore the phenomenon more directly with the senses.

In both segments, I observed that the participants were engaged, and having fun, and I would assert they were learning. With the process over, participants acknowledged the value of this type of "active learning." We also discussed the difficulties to be faced up to in this paradigm:

- Teachers must be prepared to give up being the "authority" and be willing to "dance" with the students in learning;
- What is the right balance between presenting and "processing" is an open question;
- It takes a well-informed teacher to ask the right question to dispel "wrong models" or intervene with students exercising them.

In one of the segments, participants reviewed the use of computer-based electronic mail as a means of holding "virtual office hours." This was put forth as one practice that is particularly useful for teachers of large sections. Several benefits were cited including the following: it eases the shy student coming forth; it produces more focused questions and well-developed questions; it provides a log of all questions as a by-product (for more, see the paper by Barbara Sawrey, this volume, page 64).

David R. Sokoloff facilitated a segment entitled "Engaging Students with Microcomputer-Based Laboratories and Interactive Lecture Demonstrations" (this volume, page 38). The focus here was definitely not on microcomputers but on interactive demonstrations that provided immediate feedback—in this case, on physics concepts including force, velocity, and acceleration. These particular laboratory tools were demonstrated as appropriate for use in both student laboratory experiences and as lecture demonstration aids.

We considered the involvement of college students in producing science exhibitions for 4th–6th graders. Here the college students not only produce a good science experience for the younger students but also exercise their own creativity. This extends their own learning by requiring them to teach the topic to be exhibited.

And, finally, we considered the applicability of a highly exploratory laboratory experience that simply subjected the students to several physical phenomena and then left it to them to

discover "interesting" paradigms, problems, and hypotheses within the experience.

In the wrap up of the day the following observations were made:

- Considerable innovation is available to bring to bear on the problem of education today and much of it is not too costly. One of the major challenges is making these innovations the tools of the teaching "corps," rather than just the preserve of the brave and the few.
- Monumental political barriers, and momentum in the current paradigm, impede the widespread application of these innovations.
- Current tenure/promotion practices reward research and give only lip service to instruction.
- Better teaching in the college classroom will serve to improve teaching in the precollege classroom.
- Current instructional materials (textbooks) tend to reinforce traditional lecture styles. Materials and tools to support innovative student experiences are scarce. Their development and distribution must become a priority of the academic community if instructional innovation is to become commonplace.

B. Valuing Diversity in the Educational Process
Bess C. Howard, Reporter

Summary of perspectives: Panel members unanimously commend the NSF for seriously valuing diversity in its goals for the conference. This valuing of diversity is essential at all levels—the Federal, university, local school, and personal—if the goal of improved mathematics and science education is to be realized. Our needs as a nation are more global than ever before, and the population serviced by our schools reflects a more recognized diverse set of learning styles, problem-solving and thinking styles, cultural heritages, expectations, aspirations and goals, and needs.

Valuing the diversity of the people involved in the delivery of education is also essential. This diversity is most effectively addressed by the recognition, affirmation, and development of diversity in the arenas of instructional strategies, subject matter structures and relationships, and assessment strategies. Valuing diversity requires the recognition of differences as resources, not obstacles, in the teaching and learning of science and mathematics.

The diversity panel did not attempt to define diversity, but accepted meanings in the context of presentations, which included affirmation of differences in age, culture, sexual orientation, physical abilities, ethnicity, personality preferences, and areas of content interest. Presentations recognized the need for teacher-student connections and varieties of strategies, but not exclusive of mathematics and science content.

The agreed-on long-term goal is the development of systems that respond effectively to the diverse academic needs and wants of students, that result in success for all students. In addressing this goal, in the context of valuing diversity, faculty must model and prospective teachers must learn to focus on their relationships and understandings of differences, the development of a diverse repertoire of instructional strategies, the ability to use research findings, reflecting on their knowledge and experiences in ways that improve the ability to select the most effective strategy for a given context.

The recognition of diversity as a resource, and not a problem, is supported by attention to the corollary need to acknowledge and overcome existing biases and hierarchies.

Modeling appropriate, effective behaviors is seen as an umbrella to the demonstration of valuing diversity. University faculty will communicate this more by what they DO than what they say. For example, faculty should

1. demonstrate a variety of strategies in their own instruction.
2. communicate affirmation of the diversity of their students.
3. build and utilize the resources of the class "learning community" through peer instruction, small-group projects, affirming more than one approach to solving problems.
4. identify applications of content to social issues and other disciplines.
5. use students as subjects, not just objects, of instruction.

Diverse strategies, that focus on the above behavior, imply the necessity for cross-disciplinary and interdisciplinary instruction and on the use of student learning teams to assist in the interpretation of science and mathematics content to other areas of concern and interest. Traditional content is not lost, but set into larger contexts that focus on critical thinking, holistic learning, social issues, and other arenas, with mind-engaging strategies needed by prospective teachers who must provide relevant and motivating instruction for their students in K–12 classrooms.

The basic questions to be addressed include the concept of change, which is the underlying principle of this proposal and the following outline:

1. Individual faculty members:

   - their personal changes as organisms
   - their professional needs to develop skills as agents of change
   - use of peers as observers, counselors, feedback supports
   - rewards from the institution that communicate they are valued in their new roles

2. Institutions

   - structural changes that make the new direction an essential "organ" in the life of the organization
   - rewards built into the structure for teaching collaboratively as to process as well as content.

C. Research on Learning and Teaching Science and Mathematics
Richard L. Magin, Reporter

The educational research community is eager to assist in defining the role of faculty from the scientific disciplines in the undergraduate education of future science and mathematics teachers. The theoretical perspectives, methodologies, and findings of education research are rich in examples that offer directions for change in the current establishment. Unfortunately, these examples are either not recognized widely or are not having an influence on practice. The four suggestions provided by this thematic panel address mechanisms to encourage a stronger linkage between educational research and teaching practice.

1. Develop collaborations between the educational research community and practicing teachers.

More research should be undertaken that focuses on classroom activities. Analysis of student performance should feed back to provide data on successful or unsuccessful approaches. The results should be incorporated in curriculum development efforts, and should also give direction to future research questions. Many recent research findings have not yet been examined in a whole classroom environment. Other well-known effective strategies, such as enabling the students to become actively involved in learning, are not fully utilized. Collaborations between practicing teachers at all levels (K–12, college) and educational researchers will facilitate the exchange of information on teaching and learning. This should also improve teaching practice and focus education research.

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2. *Improve communication among education researchers, teachers, and curriculum developers.*

An effort should be undertaken to distribute the theoretical perspectives, methods, and results of education research to a wider audience. The results of collaborative research will be of interest to researchers and educators in many disciplines. It is recommended that a series of high visibility education research papers be prepared and published in discipline-oriented journals. Such papers, perhaps co-authored by established scientists in a field and education researchers, should awaken interest among their colleagues in student learning, teaching effectiveness, and education assessment. NSF can help by establishing workshops that follow the model of the 1992 Gordon Conference on Teacher Education. In addition, the establishment of electronic bulletin boards could improve the distribution of information among faculty and teachers from widely separated locations and disciplines.

3. *Increase the connections between questions asked by researchers and classroom learning practices.*

The effectiveness of new teaching methods can be improved if the questions posed are more responsive to actual classroom practice. The goal here is to connect directly classroom-based research with learning practices. The outcomes of a specific research project will then provide information on the appropriateness of a particular learning model or teaching strategy. For the goals set by this NSF initiative to be achieved, the design of education research needs to accept its accountability in the "real world" of teacher experience. The formation of collaborative groups of teachers, education researchers, and science faculty should recognize the importance of these teaching/practice connections.

4. *Provide support and encouragement for science faculty and education faculty who engage in education research.*

The reward systems established by the NSF, professional organizations, schools, and universities should promote research and scholarship in learning and teaching. Teaching practitioners at all levels (undergraduate students, graduate students, professors, professional teachers) should be encouraged to explore this important and exciting field. Institutional and professional barriers to this area of research exist. New approaches to overcoming these barriers should be explored. One idea is to educate university science and mathematics faculty about education research by encouraging their involvement in NSF-sponsored research projects. In this way faculty and universities would see education scholarship rewarded in the same manner as sponsored research in a specific discipline. The enhanced support for faculty should be extended beyond a particular classroom by including provisions for textbook or software writers as well as curriculum developers.

In summary, the thematic group on "research on learning and teaching science and mathematics" addressed this question: What can educational researchers and discipline faculty do to enhance the practice of undergraduate science and mathematics and teacher preparation? The answer, in brief, is for all of the communities involved in education to collaborate and communicate more effectively with one another. In addition, the researchers and teachers involved in the process should become more strongly connected and must be adequately compensated for their efforts. This combination of cooperation, focus, and reward is needed to implement the changes in education practice that will advance the training of the nation's next generation of educators.

D. Assessment and Evaluation as a Means to Enhance Learning

Francis Lutz, Reporter

A variety of traditional and alternative assessment methods offers educators the opportunity to inform the teaching process as well to evaluate student performance. In the interdisciplinary instruction of mathematics and science, this dual role should prove particularly useful in curriculum development efforts that incorporate both theoretical concepts and their reinforcement through application.

Traditional methods of assessment may not adequately inform the teacher about conceptual understanding and the process of learning (or of unlearning misconceptions). When a thematic application is employed to increase student motivation (for example, the use of a terrarium to cover concepts of energy and mass balances), extra care must be taken in assessment to ensure the learning taking place is of what is valued in each disciplinary field. Therefore assessment methods should evaluate understanding of the processes that are held important in specific fields, but in the context of applications to problems that bring a relevance to the topic for the student. As an example, basic mathematical concepts can be covered within the modeling of natural phenomena.

Multiple forms of assessment (portfolios, basic concept inventories, collaborative testing, essays, explication of problem-solving strategies, journals, student interviews) offer the potential to accomplish many of these objectives, while aiding in the evaluation of diverse forms of accomplishment that otherwise might go unnoticed.

As our understanding of learning processes continues to be enhanced by current research findings, alternative assessment methods provide the tools to build individual instruction elements onto a foundation of classroom teaching. This aspect of improved teaching increases in importance as student diversity increases and becomes more plausible as teaching methods and technologies become available that allow responses to different learning needs to be accomplished efficiently.

Assessment has an important role to play in the preparation of teachers as well. Some would argue that today's schools are not the proper place to prepare tomorrow's teachers, unless adequate assessment mechanisms are available to measure the levels of learning that are occurring. Additionally teachers need to be more informed than is currently the case with respect to both the variety of assessment methods available to them and the potential for increased learning that results from direct student involvement in the assessment process. In this sense, assessment provides a common mechanism for communication among disciplinary teachers and educational researchers.

E. Experiences for Elementary and Middle School Teachers

Rick Billstein, Reporter

All courses designed for preservice K–8 teachers should be activity based and provide a variety of discovery-oriented experiences. Students learn mathematics and science well when they *construct* their own understanding. These courses should provide experiences with alternative forms of instruction to include not only lecture but cooperative learning groups, peer instruction, student presentations, and whole class discussions. Students should be exposed to a variety of assessment techniques including projects, open-ended problems, portfolios, presentations, and paper/pencil exams. Developing communication skills should be an important part of all classes, and the emphasis should be on learning how to learn the content and in turn of learning how to teach the content. Problem solving should be a major focus of the courses. George Polya's advice should be heeded; that is, "it is better to solve one problem five ways than five problems in one way."

The availability of calculators and computers must be addressed in courses for teachers because teachers cannot teach as they were taught during the paper-and-pencil period of education.

Although there is significant overlap in the preparation of teachers for grades K–4 and 5–8, the content needs at the middle school level are much greater than those at K–4. A specialist degree in mathematics, science, or mathematics/science is needed to teach middle school. The content of the courses for specialists must include applications of mathematics and science that children experience and are interested in.

There is a need to collaborate on the design of preservice courses. Mathematics and science educators, mathematicians, scientists, school administrators, and classroom teachers must all have input into the design of courses. Communication is needed to make the courses fit together to form a comprehensive program. In many cases, the designed courses can be team taught by faculty from mathematics, science, and schools of education.

Whether particular preservice courses should be designed for only K–8 teaching majors is cause for discussion. In science many faculty believe that courses designed for preservice teachers should be opened to non-education-majors. A long-range goal is for other courses in mathematics and science departments to be redesigned using preservice courses as models for instruction. In mathematics, preservice courses are needed with enrollments restricted only to future teachers. In these courses students can have meaningful discussions with peers who share common interests. Restricted enrollment for preservice mathematics courses eliminates non-teaching-majors looking for courses to satisfy general education requirements in mathematics. These restricted courses allow specific materials for teaching mathematics to be demonstrated, discussed, and used by students. Discussions of mathematical research on teaching, curriculum, and assessment can be included along with discussions of national standards and recommendations.

The instructors of preservice courses must be carefully chosen and have a demonstrated interest and knowledge of teacher education. If part-time faculty or teaching assistants are used for preservice courses, they must be given special training and supervised by someone who specializes in teacher education. Lecturing and listening is not an effective mode for mathematics or science learning to occur. This technique may work for lower-order learning skills but is not effective for problem solving or higher-order thinking skills.

Because mathematics and science education are in desperate need of improvement, course and program revision cannot be postponed. The National Council of Teachers of Mathematics (NCTM) has recently published curriculum, evaluation, and teaching standards. These standards were very well received and changes are taking place because of this work. Science standards must be completed as soon as possible and these standards along with the mathematics standards must be used to effect changes in teacher preparation. The instructional practices outlined in the standards must be discussed and demonstrated by preservice teachers if change is to occur. Role models are needed for future teachers.

This redesign of the teacher education program can be accomplished by faculty from mathematics, science, and schools of education working together to produce the best possible teachers. This redesign of courses is needed if future teachers are to be ready to teach the new and innovative curricula that are currently being developed. If program revision is done correctly, it can make a difference.

F. Experiences for Secondary School Teachers

William Sayle II, Reporter

The thematic group focusing on "Prospective Secondary Teachers" considered strategies that faculty in the disciplines can employ—strategies which enhance learning by all students but are particularly appropriate for prospective secondary school teachers. Discussions focused upon three major areas:

- Guided discovery/bridges to learning
- Instructional technology and materials
- Infrastructure

Guided Discovery

The curriculum should form a coherent framework within which students can develop a philosophy of what science and mathematics are and what it means to know and to do science and mathematics. The University must have a vision of what the children should know and recognize that the teachers are the bridge to the children's learning.

It must be recognized that teachers operate at the intersection of the sets of "students" (child development, psychology), "content" (discipline), "environment" (classroom, laboratory, instructional technology). The discipline providers (mathematics, chemistry, physics, biology) must help provide the content while recognizing that the education courses are providing the pedagogy and that the teacher must thrive at the intersection of these sets.

The *content* of discipline courses should demonstrate the connections and visions that scientists and mathematicians have of their disciplines. The prospective teachers should understand what the worthwhile mathematical/scientific tasks are. The deeper the understanding of the subject matter, the greater the number of metaphors and analogies that the teacher has at her/his disposal to achieve the bridge from subject matter to learning.

The *discourse* in classrooms should reflect the practice of science and mathematics. The classroom environment should nurture the students, not "weed them out." Scientific principles can be taught by hands-on examples at all levels: from prekindergarten through graduate classes in the science discipline. There are "no dumb questions, only good questions." The proper response to a "good" question is to employ the scientific method and involve the questioner in the process of answering the question. "Let the science begin," as the students develop the questions. Discovery-based learning is learning that remains with the student, long after the last final exams.

Instructional Technology

Appropriate instructional technology should be included in courses to enhance instruction and to demonstrate how science and mathematics should be done. Unfortunately, teaching methods used in the latter part of the current century do not differ significantly from those used in the early part of the century. "Chalk and talk" is still the medium preferred by the majority of teachers at all levels.

Instructional technology is becoming indispensable for companies who want to train employees to perform various tasks. Interactive computer-based expert systems are being used to train people for tasks ranging from automobile repair to emergency-room procedures for physicians.

Much has been said and written about the human–human interface and the human–machine interface. The successful interactive learning tools will be designed by teams that include the end-users. Although expensive now, the trend for increased capability at reduced cost is expected to continue in the future. The movement of textbook publishers away from traditional printed textbooks and into computer-assisted interactive tools will hasten the transition, whether or not we like it.

Infrastructure

Academic units must recognize that their mission includes the education of science and mathematics teachers and that faculty must be rewarded for participating in this mission. Collaboration must occur between education units, and the arts and sciences and computer science and engineering units. The faculty reward system in most arts/sciences, computer science, and engineering academic units does not appropriately reward faculty who participate in interdisciplinary programs.

Appropriate credit must be given for faculty participation in the education of prospective teachers. Tenure and promotion committees, as well as deans and provosts, must understand and appreciate the four types of scholarship (from Earnest Boyer):

- Discovery research (usually associated with "basic research")
- Interpretation (understanding the results of discovery research and developing new knowledge)
- Application (using discovery research and interpretation and forming useful processes and products)
- Teaching

Participation in the education of teachers should be recognized as scholarship in at least three of the above four categories.

The recruitment of our best and brightest students to become teachers is essential if we are going to improve our education in mathematics and science. One method that can be used to recruit mathematics, science, and engineering students into the teaching profession is to use them as undergraduate teaching assistants. In addition to helping other students learn subject matter, some students can be used to help develop tools for interactive learning. Successful undergraduate research opportunities programs (UROP) exist at several major "research universities." Why not instigate undergraduate teaching opportunities programs (UTOP)?

New thinking and new bridges of communication are needed between infrastructure units at all levels. Everyone will be a teacher—either formally or informally.

The Role of Life Sciences Faculty in the Undergraduate Education of Science and Mathematics Teachers

Barbara S. Beltz, Wellesley College, Chair

Panel Members: Ruth Doell (San Francisco State University), Kathleen M. Fisher (San Diego State University), Jerry Guyden (The City College of New York), Doris R. Helms (Clemson University), M. Patricia Morse (Northeastern University), Craig E. Nelson (Indiana University at Bloomington), Saundra Herndon Oyewole (Trinity College, Washington, D.C.), Crellin Pauling (San Francisco State University), Gillian M. Puttick (Technical Education Research Center, Cambridge, Massachusetts), Sidney Simpson (University of Illinois—Chicago), Carol L. Stuessy (Texas A&M University), Paul Williams (University of Wisconsin—Madison)

I. *Report of the Panel*

Introduction

Our primary goals as life science educators are to communicate to our students the conceptual framework of our discipline and to convey the excitement and energy of the experimental process. The classroom should reflect the science laboratory in generating an atmosphere of discovery. Our teaching should stimulate observational, problem solving, and critical thinking skills, emphasize crucial concepts and relationships, and provide opportunities for our students to experience the process of science—from question, to hypothesis, to testing, to resolution.

Sadly, these goals are not met in the majority of our classrooms today. Elementary-, secondary- and university-level science curricula all suffer from an overemphasis on rote learning of "facts." Consequently, most children are instilled at an early age with the notion that science is a complex body of information that is difficult to master. Remediation at advanced educational levels can do little to reverse the fact that students do not understand the fundamental conceptual framework of science and therefore possess a disorganized array of facts and misconceptions. Meaningful relationships between scientific disciplines and problems are lost, and the average student simply becomes bogged down in the details.

What is it that we, as professionals, value most dearly about our scientific lives? Would it be the facts that we have managed to retain over the course of our careers? Or would it be the finely honed skills that enable us to think critically and to be creative, to question, and to see relationships between scientific problems emerge? Surely the latter abilities are the tools of

our trade, and therefore our most prized assets. Why, then, do we mislead our students by conveying to them a vision of science as wearisome collections of facts, instead of promoting the dynamic excitement of our work? By our monologue lecture styles, our encyclopedic textbooks, and our testing of factual retention, we are telling our students that rote learning of facts is very important, when, in fact, it is our creative and critical thinking abilities that we cherish most. These skills are the linchpins of our work, and the excitement of discovery is the siren that entices us. *These* are the ingredients of science that we must learn to communicate to our students, and we must transform our educational approach at all levels in order to succeed.

The Life Sciences Panel envisions not merely an *evolution* in science education, but rather a *revolution*. We propose five major areas where the "status quo" must be redefined:

1. Curricular content must reflect an atmosphere of discovery, focus on concepts, and emphasize the experiential component of science.
2. Life sciences faculty at universities and colleges must become involved in the lifelong education of teachers in our elementary and secondary schools through workshops and partnerships.
3. Reward and tenure systems at universities and colleges must be transformed in order to encourage curricular innovation and excellence in teaching.
4. A system of external rewards and recognitions should be put in place to encourage the professional dimensions of teaching at all levels.
5. A more efficient system of disseminating information about teaching and pedagogical research must be established, so that educators at all levels can take advantage of current knowledge in the field of science education.

If these changes can be implemented, as elaborated below, we envision major shifts in both abilities and interests of the next generation of students.

A. Curricular Content

It is often said that teachers teach as they have been taught. If university faculty train science teachers by telling them *about* science (lecturing) rather than *doing* science, then it is easy to understand why these teachers later, in their own classrooms, may also present science in a passive way. Therefore, to get at the roots of curricular change, we must begin by training our teachers in a different way. The very best way to share our knowledge and enthusiasm with future teachers is to share with them what we do—the laboratory, experiments, results, analysis.... This can happen by transforming our training programs for future generations of science teachers so that the emphasis is on active participation in scientific inquiry, along with an increased emphasis on the numbers of science courses that must be taken to be certified as a science teacher. Both the quality and the amount of science training are important for future teachers to believe that they are active and confident participants in the sciences. Enhancement programs for teachers already in the field, through partnerships and workshops, are also a necessary component of the systemic change we propose.

Experiential learning is clearly important in the training of scientists and science educators alike. Science curricula must also focus on concepts, issues, and critical thinking, rather than on rote learning. With emphasis on concepts and issues, breadth of material covered will be sacrificed for increased depth of understanding. This compromise is acceptable, because in this case, "less is more." With a new focus on experiential discovery-oriented learning, combined with emphasis on fundamental concepts, our expectation is that student enthusiasm will swell. Creating renewed interest in the life sciences is one of the first steps toward revitalizing our discipline.

B. Bridges between University Science Faculty and Elementary and Secondary School Teachers

The academic agenda outlined above is ambitious, and specific recommendations are necessary for *how* we may accomplish such sweeping curricular change. It is of utmost importance that university science and education faculties work closely together to restructure the course of study for future life scientists and educators. The lack of communication, in most settings, between education and science departments is of great concern. Those faculty that study and best understand the art of teaching have very little interaction with the faculty that *practice* the art. Both groups can learn from each other: the scientists should learn what current research in teaching can tell us about the ways that students learn best, while education faculties can learn about how science works and the conceptual underpinnings of the field.

To enhance existing K–12 science programs, the panel suggested forging liaisons between university and elementary/secondary school teachers. The purpose of these partnerships is to focus on *how* science is presented to students at all levels, and to provide resources for discovery-based learning. Two specific types of university faculty/K–12 teacher partnerships were proposed: (1) summer or weekend workshops that would expose teachers to interactive learning methods, useful classroom demonstrations, and laboratory exercises for their level in the life sciences; and (2) "science-to-go" programs, developed by university faculty in collaboration with K–12 teachers, would promote interactive science activities that are "packaged" for teachers to take to their classrooms.

1. *University/Teacher Partnerships*

One suggested model for a liaison to enhance elementary and secondary school science programs is for university/college faculties to offer 4–6 week integrated summer science programs for teachers. Teachers enrolling in the program would be required to devote two consecutive summers to the partnership: during the first year they will experience first-hand the proposed teaching tools; in the second year, *they* will become a valuable teaching resource for the program. We see the following benefits to this arrangement: We are hopeful that the program will become self-sustaining, with returning teachers taking increasing responsibility for the learning environment in the partnership classroom. Teachers will leave at the end of the first summer with the knowledge that it is their responsibility to test and evaluate the new classroom methods and exercises and to bring back the following summer a serious assessment that can be used for revision of teaching materials. In the second summer, the methods of the first summer program can be reinforced and specific problems in the classroom can be addressed. Perhaps most important of all, a 2-year formal partnership will enable the teachers to have on-going support during their first "implementation" year.

Budgetary constraints will certainly have a major impact on the success of any new science programs in our schools. Although all demonstrations and experiments should be designed to require minimal equipment and supplies, increasingly tight school budgets could easily squelch a new program, no matter how creative, if any cost at all is associated with it. It is proposed that partnership programs would send each teacher back to his/her school with an "award" for having completed the program. The "award" could consist of money, supplies, or equipment adequate for implementation of the partnership curriculum. Such a financial award would also provide recognition for the teacher(s) within their home schools. NSF can be instrumental in promoting partnerships by sponsoring such programs financially.

2. *Science-to-Go*

The second type of outreach program discussed by the Life Sciences Panel is to promote interactive science activities packaged for teachers "to

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go." Such a program would include a booklet of simple instructional materials that would offer suggestions for creative classroom demonstrations at the middle school [elementary, etc.] level. These written materials would be constructed by university/college science faculty in collaboration with K–12 teachers. The packaged materials would also include all the necessary materials to conduct the demonstrations described in the booklet. Introductions to the materials could be provided in short (2–3 hour) sessions by faculty volunteers.

The Science-to-Go curriculum should address the following educational goals:

1. Demonstrations/exercises should provide a vehicle for generating excitement and creativity in a classroom setting using minimal resources.
2. Basic chemical and biological concepts should be integrated as much as possible, and interdisciplinary areas should be underscored.
3. Students should be involved with problem-solving tasks.
4. Experimental design should be discussed.
5. Each exercise should sharpen critical thinking and writing skills and should include "peer" review by the students.
6. Connections with the "real world" should be emphasized in order to help students connect science with their everyday lives.
7. Group learning tasks should be included.

C. Reward and Tenure Systems at Universities and Colleges

In order to accomplish the sweeping changes proposed for our life sciences classrooms, our university and college faculties will be required to make a major commitment of time and energy. At the present time, there is very little incentive for faculties to take on such responsibilities. On the contrary, with tenure and promotion decisions at most universities depending most heavily upon research progress, there is a distinct *disincentive* to becoming involved in curricular issues. It is ironic that so many of our institutions of "higher learning" have largely removed themselves from the pursuit of pedagogy by their unbridled devotion to scientific research. Our graduate students in the sciences learn very early that research is *the* priority: Although many programs do require some teaching to earn the Ph.D. degree, this is regarded in most institutions as "putting in the time," rather than an important apprenticeship that should be treated with utmost dedication. Consequently, it is generally the "born" teachers that flourish, while the rest struggle to a greater or lesser extent in their classroom efforts. Why don't our life science graduate programs incorporate courses to train students in the art of teaching? How can we expect that our institutions of higher learning will remain top quality in terms of teaching when, in fact, the science faculties have little or no experience, and no formal training, in the teaching profession? With the combined lack of formal classroom training, and the disincentive to invest oneself in teaching once a faculty position is obtained, it is no wonder that our classrooms have major problems today. Although universities and colleges have begun to pay lip service to the problems of their tenure and reward systems, a strong commitment to change is not yet evident. This state of affairs must be reversed, so that our best scientific minds are also attentive to and involved in classroom issues.

The *only* way to encourage our faculties to become *interested* and *invested* in teaching is to reward success in the classroom. Instead of viewing teaching as "taking away from" the research effort, our thinking must be turned upside down so that the classroom is not only a responsibility, but a positive challenge that is to be respected. The classroom can, and should, be every bit as exciting as the laboratory. Our university and college faculties need to be encouraged, supported, and nurtured in this effort. These incentives must include a change in the tenure and reward system so that the profession of teaching holds a stature equal to that of experimental research.

D. External Rewards and Recognitions to Encourage Teaching

One of the reasons that research holds the high esteem of our university administrators and faculties is that research brings money in the form of overhead. For many schools, research dollars are the life-blood of the institution. In addition, the pace of publication of scientific data gives the institution valuable exposure. This situation has fueled the zeal for research, while classroom efforts go largely unrewarded. The lack of institutional financial rewards and visibility for teaching efforts has trickled down to the level of tenure and promotion qualifications. It is unlikely that this situation will change until institutions are also rewarded for their promise in the classroom, perhaps in the form of overhead on equipment grants for instructional purposes. Alternatively, some proportion of institutional indirect costs on research grants could be earmarked for classroom needs. There should also be some mechanism for providing national recognition to institutions for innovative or particularly effective teaching programs. Such positive efforts to compensate and honor institutions that openly encourage faculty to invest themselves in the classroom will help to raise the faltering esteem for the professional aspects of teaching.

E. Establishing an Efficient System of Disseminating Information about Teaching and Education Research

One area the NSF Life Sciences Panel discussed at some length is the problem of sharing of information between scientists and professional educators that study processes of teaching and learning. Although many publications are available in the field of science education, this field is not widely known among the university/college science teaching faculty. Therefore, although new pedagogical methods may be available, these methods do not infiltrate rapidly to those who might benefit from them most—the scientists who are in the university and college classrooms. We therefore urge the NSF to orchestrate a mechanism for making education research in the life sciences readily available to the research and teaching communities. This could be a direct effort by publishing a newsletter for science educators, or facilitation by funding the efforts of private groups (such as the Coalition for Education in the Life Sciences discussed below) to disseminate such information. It was also agreed that science departments at universities and colleges should include in their library acquisitions education journals that are pertinent to life science educators. Examples of such journals are: *Journal of Biological Teaching, Journal for Research in Science Teaching, Science Education, Journal for College Science Teaching, Science Scope, Science Teacher*, and the ERIC database. The presence of such resources in science libraries will make information about classroom issues more readily available to research/teaching faculties and will also increase the visibility of professional research in science education.

Conclusion

Progress toward these goals is already visible. Many universities and professional societies have begun to make positive efforts to improve the classroom experience. For instance, Coalition for Education in the Life Sciences (CELS) was formed in 1991 by individuals from 30 life science organizations that represent over 250,000 professional scientists and science educators. The goal of this group is to mount a coordinated effort of national organizations working together to improve life sciences education. At CELS conferences (1991 and 1992), very specific guidelines and recommendations have been drawn up that are completely consistent with the views of this NSF Life Sciences Panel. The specific motivation of CELS is the "overall belief that science, especially the life sciences, must be part of a core of knowledge for all Americans if they are to participate fully in our society..."[1] Toward this goal, the CELS II conference, like this NSF Life Sciences Panel, proposed a complete makeover of the system of science education in the United

States. The specific "ingredients vital to a necessary overhaul..." include the recommendation that science should form a core consisting of 20% of the undergraduate curricula and that students in the K–12 years should be the recipients of hands-on, inquiry-driven science education. The CELS II conference acknowledged the need for vast new resources, including "endowed chairs, adequate provisions for support staff, and grants for curriculum development at the college and university level." Like the NSF Life Sciences Panel, CELS II also encouraged closer interactions among teachers, researchers, and college/university faculty to "maintain a close collaboration in this endeavor."

Other initiatives to improve the quality of science education in this country are also apparent. The Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA) has funded a project to develop new curricular materials to teach high school students about the brain and nervous system. This Science Education Partnership Award (SEPA), granted to the National Association of Biology Teachers (NABT) and the Society for Neuroscience, has already brought teams of high school biology teachers and neuroscientists together for a 4-week workshop at Wake Forest University in North Carolina. The teams were drawn from 17 states, and each team was matched by geographical location so that the teachers involved would have the support of a nearby neuroscientist. It is the Society's hope that teaching materials developed from these partnerships will eventually provide prepackaged lesson plans that can easily be adopted to fit a variety of needs.

The crucial message for all of us, as scientists and educators, is that we need to form a fresh vision of what science education should be. It is obvious to all that a monumental effort at many levels in our educational hierarchy will be required to make effective changes in current curricula. The need is critical and the price is high. But life sciences education and literacy for generations of children are at stake. The question does not appear to be *whether* to incite a revolution in life sciences teaching, but rather *how fast* the proposed changes can be implemented. The members of the NSF Life Sciences Panel unanimously agreed that science education in this country is facing an emergency situation and that quick action at all levels is required.

[1] National Life Sciences Education Conference II (CELS II). Coalition for Education in the Life Sciences. Executive Summary. 1992. Available from the Office of Education and Training, American Society for Microbiology, 1325 Massachusetts Avenue, NW, Washington, D.C. 20005.

II. Reports from Thematic Group Representatives

A. Instructional Innovation

Sidney Simpson, Reporter

The Instructional Innovation Panel presented a variety of innovations, many of which could easily be incorporated into the teaching of life sciences at the undergraduate level. Moreover, many of the innovative approaches presented would well serve primary and secondary school teachers, for they project the dynamic nature of teaching and pedagogy. They, as we shall see, also communicate the excitement, the risk taking, the uncertainty, and the collaborative interactions that are characteristic of the way science is done. These innovative approaches should be part of our training of prospective primary and secondary teachers.

Most of the innovations presented by the panel centered on collaborative and active learning. Dr. Gillian Puttick described a number of peer interaction formats that can be used in small working groups as well as in large lecture courses. These interactive/collaborative approaches, "encourage students to think issues through, to clarify their thinking, and to articulate their thoughts" [Gillian Puttick]. In one such approach, student partners work on a problem individually for a short period of time, then break to interact in a "dyad." Here they take turns talking to each other about the problem or about their feelings about the problem. After the

"dyad" each returns to individual work on the problem. This cycle is carried out until both partners feel they have reached a solution. Dr. Puttick also pointed out that the "dyad" interaction can also be used in large lecture classes. Here, one can invite the students, at the beginning of the class, to turn to each other, form dyads and take turns (1 minute each) talking and listening to each other—about anything. Then as the lecturer completes the explanation of a particular concept, the dyads are asked to take turns (1–2 minutes) explaining the concept to each other. This gives them a chance to see if they really understood and can articulate the concept and, if not, to formulate questions to ask the lecturer. Dr. Puttick also described ways in which the dyad concept can be used to facilitate "brainstorming" among groups of three to four students, working on a complex problem.

Dr. Sarah Berenson presented several approaches to both *collaborative* and *cooperative* learning. Here, cooperative learning is a more structured subset of collaborative learning applicable to mixed-ability groups. Cooperative activity may well involve mastery learning while collaborative learning almost always involves inquiry activity. In one small-group (three to four students) collaborative project, the students work individually on three questions related to the inquiry activity. They are also provided with manipulables they can use for modeling solutions to the questions. The group then progresses toward a collaborative solution through several steps: use of prior knowledge, group investigation, and group reporting. In this approach, each participant brings to the problem their own unique experiences, misconceptions, and knowledge. This approach to learning could replace the often unproductive discussion sessions associated with many college courses. Likewise, if prospective teachers are taught by this approach, they are more likely to incorporate this approach in their own teaching.

Dr. George Moore described a highly innovative approach to teaching science that involved providing students with laboratory equipment they can use to measure and experiment and a set of tasks to perform. From the observations and data collected, the students are to each select some interesting result or observation. They are then to devise hypotheses to explain the observations. They then devise experiments to test one or more of the hypotheses. This very open-ended, high-risk approach provides the students with a much more realistic view of how science is done and enables the student to experience some of the anxiety and excitement that is science.

Two additional innovations involved mechanisms of stimulating interactions between lecturer and students in large lecture classes. Dr. David Sokoloff presented a series of demonstrations that introduced concepts and interrelationships related to force and motion. The demonstrations involved microcomputer-based tools that enable a physical demonstration to be carried out, the results plotted and projected on a screen in real time. Each demonstration is preceded by a description, and in each case the students are asked to predict the outcome graph. The demonstration occurs, the results are immediately graphed, and the students can compare their predicted graph with the real graph. They can begin to ask why their prediction differed from the real result. This approach, even in a large lecture class, enables students to participate, i.e., form hypotheses and modify them. Although the examples presented related to physics concepts, one can easily see how this approach could be used to teach biological concepts, concepts such as population growth, predator/prey relationships, enzyme kinetics, etc. As Dr. Sokoloff pointed out, the immediacy of the presentation of the graphs of the physical demonstrations have a demonstrable effect on retention and understanding.

Lastly, Dr. Barbara Sawrey presented an innovative approach to office hours for large undergraduate classes—the "electronic office hours." The system she described was designed for large freshman chemistry classes. Each student was given a computer account and instructed how to use e-mail. Thus, students that had questions about lecture material could send their

questions to the lecturer and the TA's in the course. Lecturer and TA's could then sit down and answer the questions at their leisure. As most of us know, few students usually make good use of faculty or TA office hours. By contrast, Dr. Sawrey reported that, using the electronic office hours, students accounted for 4600 logins in one 10-week quarter. Student questions and the faculty responses, stripped of identification, were routinely printed and posted each week.

The approaches highlighted above will improve learning for all students. And, they are especially important for prospective teachers. They are important because they stimulate interest in scientific inquiry; they stimulate a pattern of lasting curiosity that encourages continuing learning; and they reinforce for teachers the view that this is how science should be taught. These innovations are likely to have a major effect on the subsequent teaching style of prospective primary and secondary school teachers.

B. Valuing Diversity in the Educational Process
Ruth Doell, Reporter

The following main points were summarized by the panel that discussed diversity in the science classroom:

1. We commend NSF for taking diversity ever more seriously.
2. "Valuing Diversity" applies to student heterogeneity generally: preparation, goals and aspirations, learning styles, personal and group attributes, and history.
3. Diversity is a resource, not a problem. Corollary: We need to come to grips with existing biases and hierarchies.
4. The use of a heterogeneous mix of teaching strategies in college science courses is the key to valuing diversity:

   - Diverse ways of learning and excelling will foster success by all students and will help them develop an appropriate sense of competence.
   - Strategies that enable diverse students to excel will thereby foster an appreciation of diversity among students. This is of central importance for prospective teachers.
   - Heterogeneous approaches to teaching by disciplinary faculty will model discipline-appropriate teaching and assessment strategies for prospective teachers.
   - The heterogeneous approaches used will usually include some that can be modified and used by many teachers and others that are central for adult learners in the discipline, but may not be as appropriate for many preadult learners.

5. One of the most important groups of strategies includes those that develop collaborative student learning groups and communities. These range from simple pairing for 3-minute discussions to the formation of term- or year-long project teams
6. We need to prioritize traditional content by setting it into larger contexts, contexts that focus on major theories, critical thinking, valuing and social issues, and connections with the students' own interests and lives.
7. It is essential but not sufficient for disciplinary faculty to use diverse teaching strategies and otherwise value diversity in the courses they teach. It is also essential to involve them more deeply in explicit, subject-matter-specific, teacher training in ways that range from the sharing of pedagogically powerful activities through the processes of planning particular teaching units and connecting with discipline-based information networks.

It was also clear that particular issues related to diversity are especially relevant to the life sciences. In the discussion of the need to increase participatory and cooperative modes of learning, the need to listen to *all* the students and to let ourselves learn from the experiences of those who are different from us was emphasized.

Implied in this is the right of those students to be heard when they suggest changes—in the kinds of questions asked by scientists and the kinds of issues raised (including social ones) by the doing of science, as well as their right to be represented in the groups who benefit from science. For example, when cooperation in the classroom is emphasized, the advantages of cooperation in research can be discussed. This type of cooperativity is exemplified by the groups working together under Nancy Wexler's direction on the Huntington's disease gene.

Discussions in the diversity panel also focused strongly on bringing more of "status quo" science, such as DNA research and the latest in computer technology, into the classroom. There is nothing wrong with such activities; they do excite the students and teachers, and they help students to learn. But they are limited in their ability to deal with the critical issues of equity and bias in society. Focusing on DNA technology (as one example) means that this type of research is deemed appropriate, and when ethical questions are raised (if they are), they will be ones concerned with the safety of the techniques and products, not questions of who benefits from the research or who pays for the increasing cost of, for example, health care, brought about by the commercialization of this technology.

Finally, it is obvious that more interdisciplinary collaboration is needed in the science classroom to integrate the science that is learned there into ideas and issues raised in other courses. One consequence of this would be that the content of our courses would need to be broadened, and it will have to include criticism of science that is biased or ideologically based. Discussions in science classes can address the interests of a variety of ethnicities, races, genders and classes, particularly classes other than the middle class to which most at this meeting belong.

C. Research on Learning and Teaching Science and Mathematics

Kathleen M. Fisher, Reporter

Science education researchers are well aware that there has been a dramatic paradigm shift in science education during the past decade, resulting from the convergence of research findings from many different fields, including cognitive science, cognitive psychology, philosophy of science, sociology, and science education. Because of this convergence and because of the incredible value of the computer as a tool for studying and modeling cognitive functions, educational experiences can now be designed on the basis of relatively sound cognitive learning theory. Furthermore, much of the earlier educational research must be reinterpreted and in some cases discarded altogether, because its basic assumptions are flawed. Yet few teachers at either the college or precollege level are aware of this revolution. The concerns of the research panel centered largely around this disparity.

The science education researchers who presented their work to the panel were unanimous in their recognition (a) that educators need to focus much more on promoting meaningful understanding and (b) that teaching more [depth] requires teaching less [breadth]. The presenters demonstrated the strategies they have been developing and testing for promoting deeper understanding by their students.

These discussions led to the first key question: How do we effectively disseminate the results of educational research? This is a difficult problem for many reasons, which include (a) the subtlety and complexity of cognitive theory such that it requires thoughtful, intelligent application by an informed instructor, (b) the current situation wherein precollege teachers generally have a low level of science knowledge and frequently fear or dislike science, (c) the prevalence of "prescience conceptions" or "misconceptions"

among teachers and students alike, and (d) the profound nature of the revolution that has occurred in thinking about learning, including recognition that many of the strategies that have been developed in the past few decades for efficient instruction and testing of large numbers of students may be directly responsible for the declining performance of American students and must be changed.

In general, people tend to teach as they've been taught. It is tremendously challenging first to achieve a deep change in one's world view (from behavioral to cognitive in this case) and then to change one's teaching practices on the basis of this rethinking. That is, it is difficult to invent ways of teaching ourselves that we have not personally experienced. The transition from primarily rote to primarily meaningful learning, and from viewing knowledge not as an accumulation of factoids but rather as a single integrated, interrelated whole, seems especially demanding. The situation is further complicated by the fact that most college life science instructors believe they are teaching for meaningful understanding now. Because they do not read the educational research literature and do not assess their own students in ways that reveal the levels of student understanding, college biology teachers are not aware how little many of the students in their classes actually learn. More effective dissemination of science education research findings would help to increase awareness of the problem—an essential first step.

Researchers are concerned with not only how we teach but also what we teach. Life science educators could make good use of the precollege years, for example, to systematically construct the intellectual foundations necessary for deep understanding of the "big" ideas in their field. For example, to lay the groundwork for understanding evolution, precollege students might study (in a hands-on way) population dynamics, mortality rates, survival rates, mutation rates, etc. To understand dynamic processes in living systems, precollege students might study (in a hands-on way) the behavior of matter and its particulate nature, including such phenomena as diffusion, osmosis, electrophoresis, etc. This notion of teaching "protoconcepts" or providing systematically structured early experiences that can serve as stepping stones to the important ideas of a science contrasts markedly with current practice, wherein earlier grades receive watered-down versions of what is taught again in later grades.

The basic rule of thumb that teaching more means teaching less is especially problematic in the life sciences, where what is known continues to mushroom at an astounding rate. With more knowledge to teach every year, how can we possibly teach less (i.e., fewer concepts)? And, if we are to focus on depth of understanding rather than breadth of coverage, what do we keep and what do we throw out? Even though some advances, especially those involving powerful new theories, tie things together and therefore simplify rather than complicate learning, this issue is not a simple one to solve.

Related to this is the interplay between process and content. How do we achieve the right balance between developing conceptual understanding of the ideas of science and developing knowledge about how science is done and how we know what we know? Can we develop consensus on what is important to teach?

Technology is potentially an aid in this transition, providing valuable support for reorganizing classrooms and restructuring students' learning experiences. However, it also presents a formidable barrier, especially for the majority of precollege teachers who have yet to touch a computer. Where are the resources to equip the schools and train the teachers to make the highest and best use of the available technology?

The panel believed that engaging practicing teachers in "action research" (i.e., research on teaching and learning) in their own classrooms is an effective method for disseminating and testing science education research findings. When teachers become involved in research projects, they are prompted to read the research literature, they can repeat key studies to convince themselves that the findings are indeed applicable in their own classrooms, and they can

obtain direct feedback about their change efforts. Ongoing research and frequent diagnostic testing is valuable to monitor both student learning and instructional/teacher effectiveness. The panel believed that much more research is needed on undergraduate learning in the life sciences.

In summary, the Life Sciences Research Panel identified a number of key issues, some of which are summarized below:

- How do we effectively disseminate the results of educational research, especially to precollege and college teachers?
- How can we upgrade teachers' science knowledge and their confidence in teaching science?
- Can we change what is taught at the precollege level so that students are better prepared to grasp the main ideas of the life sciences?
- If we are to focus on depth of understanding rather than breadth of coverage, what do we keep and what do we throw out?
- How do we achieve the right balance between developing conceptual understanding and developing knowledge about how the ideas of science have come into being?
- How can we develop consensus on what is important to teach?
- How can we equip schools and train teachers to make the highest and best use of available technology, so as to facilitate the transition to more meaningful learning?
- If we assume that action research is a good vehicle for dissemination of educational research findings, how can we engage more college and precollege instructors in action research programs?

D. Assessment and Evaluation as a Means to Enhance Learning

Doris R. Helms, Reporter

Student assessment and course evaluation can be used as powerful tools to enhance teaching and learning in science, mathematics, and engineering undergraduate classrooms. Traditional methods of assessment, however, fall short of this promise. Tests designed to measure what students know often measure only what students do not know. In most classrooms, few opportunities are provided for undergraduates to demonstrate how they know, what they think or understand, and how they can use what they have learned. Students are given little time to reflect on their own or to engage in self-assessment. Faculty tend to use assessments as diagnostics rather than prescriptions for change that inform their own teaching and provide future teachers with models of improved instruction.

To enhance teaching and learning, we clearly must alter assessment instruments, assessment methods, and how we interpret and use assessment results.

1. **Assessments must be designed to be more meaningful to students.** These should enable students to relate to real world problems that create a "need to know" on the part of students. New assessments should provide students with opportunities to apply knowledge and skills to solving new problems or exploring novel situations. Above all, new assessments should enable students to identify their own strengths and weaknesses.
2. **Faculty must make use of and learn how to interpret assessment results.** New assessments must provide faculty with information that will enable them to redress student misconceptions, evaluate student understanding, and respond to different student learning styles. Most importantly, faculty must learn to use assessment results to evaluate the effectiveness of instruction and to modify their practice.
3. **Assessments must measure what scientific communities value.** These should encourage students to achieve higher levels of cognition, engage in the process of scientific reasoning, and demonstrate not just what they know but how they know it. Assessments should require students to base their understanding on the analysis of data or evidence to support hypotheses and should reflect the practice of the discipline.

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To accomplish these changes, we must begin to use multiple modes of assessment. Shulman (1988) claims that an accurate profile of a student's knowledge can be obtained only when a variety of assessment modes is used. These include both traditional and alternative assessments as well as performance-based and authentic assessments. Alternative assessment implies assessment tasks that are not traditional paper and pencil, multiple choice, short answer, or essay tests. Alternative assessments are nonroutine and provide students with a means to demonstrate their strengths and understandings. Performance-based assessments are used to measure what students can do while authentic assessment usually requires the evaluation tasks to mimic activities in the discipline.

Portfolios, concept inventories, journals, laboratory notebooks, laboratory practicals, collaborative testing, or student interviews are just some of the forms of alternative assessments that can be used as a means to evaluate what students have learned and understand. Angelo Collins (1992) describes the use of portfolios as a means to demonstrate that students have not just mastered facts but have constructed their knowledge in a meaningful way. Collins describes portfolios as containers of evidence related to a goal. Portfolios enable students to demonstrate growth and change through time as they progress toward their goal. Each piece of evidence captured in the portfolio adds value, in not only what it is but why the student did it. Students can show off their own strengths and talents rather than conforming to a set of talents prescribed by traditional assessments. The instructor and students together may decide the nature of the portfolio by determining goals, by defining the amount and types of evidence to be included, and by deciding how the portfolio will be reviewed and used. While engaged in this process of decision making, both students and instructors reassess what is worth teaching and learning. As a result, instructors will change what and how they teach, and students will change what and how they learn.

Use of collaborative problem-solving activities (Champagne, 1993) that engage students in behaviors that are more like those of the work-a-day world also offers an alternative approach to assessment. In the classroom, we usually isolate learning and test students on their individual knowledge. In the laboratory, students may be encouraged to work in groups, but they continue to be tested as individuals. Collaborative problem solving and group testing have the potential to promote cooperation, improve communication skills, and develop a sense of responsibility on the part of students. These characteristics are highly valued in the work force, but remain untutored in our traditional teach-and-test situations.

Knowledge of what research has to say regarding problem-solving strategies is a necessity for faculty who rush to engage in construction of problem-solving forms of assessment. Mestre (1993) points out that problem solving is approached differently by experts and novices. Experts tend to focus on principles and concepts that address the problems to be solved and then concentrate on developing a strategy to apply them. Novices, however, focus on strategies to solve the problem first—identifying and solving equations or manipulating variables, without attention to underlying concepts or principles (Mestre, 1993). To teach students to solve problems as experts—to do what we do as scientists—Mestre asks students to write problem-solving strategies before engaging in the actual problem-solving process. Such strategies are modeled each time problems are solved in the classroom or laboratory. The ability to write strategies not only improves students' abilities to solve problems, but improves their ability to identify principles that underlay the means to solve the problem.

Informed instruction, or the knowledge of how students think and learn, also requires us to deal with student misconceptions—those commonplace beliefs that, if not addressed, cause students to approach learning in a memorization mode. Hestenes, Wells, and Swackhamer (1992)

explore student misconceptions in physics—those of force and motion. They point out that instruction which does not take these misconceptions into account is ineffective. Hesteres and coworkers describe an inventory (*Force Concept Inventory*) designed to explore student beliefs and how they compare with conventional scientific (Newtonian) concepts. The inventories also provide instructors with data to assess the effectiveness of their own instruction. Knowing what the misconceptions are, however, does not improve learning by itself. Well designed instruction must follow if students are to understand what they learn.

These and other alternative modes of assessment can be used in a variety of teaching environments. In the laboratory, investigative, problem-solving techniques are replacing more traditional "cookbook" laboratories that simply require students to read and follow directions. Robert Kosinski and Jean Dickey (see Helms, 1993) have successfully merged computer technology and video to support investigative biology laboratories for large course operations (approximately 1100 students). Students engage first in a simulation designed to assist with developing hypotheses and formulating strategies to test the hypotheses. This is followed by three wet lab units that require students to design and perform their own experiments. Collaboration and communication skills as well as laboratory skills are enhanced by this approach. More, importantly, students come to understand science as a process—a way of knowing—rather than a collection of facts or lists of directions. Skill assessments are performance based. Authentic assessments require that students write research reports and present projects.

In the lecture hall, even traditional methods of assessment can be altered to enhance learning. Advanced Placement examinations of the College Board include free-response sections that are designed to evaluate a student's understanding of a concept, interrelationships among concepts, or to apply knowledge of principles and laboratory techniques to solve novel problems. Large numbers of essays can be graded accurately using standards developed by graders (Helms, 1993). This process can be transferred to students who can be made responsible for their own grading. In writing standards, students develop a deeper understanding of the problem or concept being addressed. The "need to know" enhances the level of student learning, improves understanding, and develops communication skills. Large lecture classes may also be enhanced by student journaling (often electronic), mentor interviews, and collaborative problem-solving recitations. These can all be used as a means to assess student progress, understanding, and learning, as well as a way to improve teaching.

In the lecture or laboratory, and in small or large classes, new technologies are being explored. Computers, often found in computer laboratories and used for individual instruction, are making their way into small classrooms and large lecture halls where they are used, in combination with video and audio, for interactive multimedia presentations. Computers can also be used for electronic office hours, for communication among students in the classroom, or beyond the classroom. Analyses of these interactions can be used by faculty as a means to follow student progress along the learning continuum.

Computer-intensive courses differ in both content and pedagogy from traditional courses (Heid, 1993). Heid's *Computer Intensive Algebra* curriculum places emphasis on reasoning rather than manipulation, the use of multiple strategies, cooperation among individuals in a group, and application of algebra to real-world situations. The computer allows for discussion about a greater range of representations or examples. Students can access large amounts of data, both analog and visual, to assist them in forming strategies for problem solving, conceptualizing, or applying new knowledge. The teacher becomes more of a facilitator while the student becomes more and more responsible for his or her own learning. Using computers and multimedia, assessments can be designed to enable students to demonstrate individual learning styles and strategies and to take advantage of the

wealth of information that can be used in the testing environment without having to provide everything in a paper and pencil format.

Whether traditional, alternative, performance, or authentic assessments are used, the process of assessment must be on-going. Only in this way can students construct knowledge or learn to learn and understand. K–12 classrooms and universities must also engage in a continuum, learning from one another. Students do not "start over" when they reach the college classroom, yet they are often taught and assessed as if this were the case. We must learn from each other and strive to better identify what students need to know and how they need to be taught. Assessment promises to give us these answers if properly designed, practiced, and interpreted.

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E. Experiences for Elementary and Middle School Teachers

Crellin Pauling, Reporter

1. *Acquisition of the Subject Matter Base*

The panel agreed that the acquisition of the subject matter base for both prospective elementary and middle school teachers should be with active, hands-on, discovery-based learning. Powers of observation should be honed, collaborative learning encouraged, and group problem solving should be employed in the instructional process. The principle of less is more was endorsed, with a strong belief that the goal should be an understanding of principles rather than memorization of a mass of facts. A cross-disciplinary approach to the instruction is encouraged, particularly for the prospective elementary teachers.

The panel also agreed that we at the university level need to involve inservice teachers in the design and planning of curricula and courses that serve preservice teachers.

2. *Should There Be Separate Courses for PreService Teachers?*

There seemed to be a consensus among the Panel that in the best of all possible worlds there should not be separate science courses for preservice teachers in the science disciplines. However, there were differences as to the design of the courses that would at the same time serve preservice teachers, the general student, and science majors. The consensus was to study the various models and to obtain objective data as to their effectiveness. (The Panel did accept the arguments of Rick Billstein that separate courses for preservice teachers are desirable in mathematics.)

3. *How Should the Preparation of Elementary Teachers Differ from that of Middle School Teachers?*

The consensus of the Panel was that middle school preservice teachers should have a more

intensive foundation in science and mathematics than elementary teachers. In addition, the Panel endorsed the concept of science specialists and mathematics specialists at the middle school level.

4. *Strategies To Fix Our Own Ship*

It was generally agreed among the Panel members that there is considerable room for improvement in the teaching of science at the university level and that it is incumbent upon us to effect changes in our approach if we want to effect change in the teaching of science at the K–12 levels. Strategies proposed include the following:

- the use of interdisciplinary labs in conjunction with the regular lecture courses, in lieu of the normal lab section.
- the integration of curriculum/instruction/assessment in model systematic programs, which include a strong faculty development program.
- involvement of professional organizations in support of science teaching.
- revision of the faculty reward structure to include a legitimate component of teaching excellence, based on an objective measure of specified goals and outcomes.

5. *Research and Development Agenda*

We need to work together to develop and promote a strong research and development agenda for science education, one that includes objective assessment of outcomes. A strong research base of teaching and learning strategies is essential, with publication of the results in refereed journals. This research should be encouraged, funded, and rewarded in the same way that bench research in the basic disciplines is encouraged and rewarded.

F. Experiences for Secondary School Teachers

M. Patricia Morse, Reporter

Part of the college and university mission is to prepare undergraduates who wish to pursue a career as teachers in the secondary schools. If these prospective teachers are to be life science teachers, these young people need to be exposed to a rigorous education in the discipline. The context of the subject is best provided by scientists who are active participants in the scientific discipline.

However, teaching of science is not the exclusive domain of the discipline professor. There is a need to ensure coordination with education faculty, discipline faculty, and liberal arts advisors to set a curriculum for prospective teachers that will provide them with elements of guided discovery, conceptual content of the particular life science discipline, familiarity with up-to-date technology (especially relative to the uses of computers), a quality environment for nurturing the prospective teacher, and an opportunity for informal teacher–student interaction.

Discipline faculty should be guided to convey the excitement of science, provide context for teaching based on research and creative activity, and utilize information technology to enhance the teaching environment. Special attention is needed in teaching the introductory courses in science to create a conceptual basis of learning and include interactive laboratory sessions. There is a need for the discipline faculty and their respective administration to build infrastructure to reflect the mission of undergraduate departments to teach and encourage prospective teachers.

For anyone teaching in the life sciences, it must be recognized that there is a need to be a lifelong learner. There are continuous changes in the existing scientific paradigms and new discoveries should be reflected in all levels of curricu-

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lum development and exchange. Provisions for new learning, new technologies, and hands-on activities should come from the discipline faculties. In creating centers for lifelong learning, bridges of information exchange should reflect a two-way flow of information to include pedagogical research advances appropriate to the students and teaching environment and consideration of the resources available to the teachers. Creativity and use of new ideas and technologies for teaching life sciences would benefit with scheduled follow-through activities to assess classroom value of the activity, encourage innovative adaptations of curricular activities, and re-evaluate the methods. In the activities, new infrastructure to increase respect and understanding between faculty from schools of education, faculty from life science disciplines, teachers from secondary schools, and scientists from research units (from industrial, government, and academic institutions) must be created and nurtured.

Special recruitment is needed to encourage the education of science teachers. More interest in this subject by the professional scientific societies through programs of highlighting teaching careers and professional meetings, including teachers in society activities, valuing and rewarding teaching, and including teachers in gathering scientific research data are all possible ways to increase the professionalism and excitement of the careers of our life science secondary school teachers.

Most importantly, we must develop new ways to reward teachers, those who wish to become teachers, and those who facilitate new research in teaching. In particular, focus and creativity is needed to assess the role of teaching evaluation in the tenure process of universities and colleges.

The Role of Mathematical Sciences Faculty in the Undergraduate Education of Science and Mathematics Teachers

Fred S. Roberts, DIMACS, Rutgers University, Chair

Panel Members: Michael J. Arcidiacono (The Math Learning Center, Portland, Oregon), Sarah B. Berenson (North Carolina State University), M. Kathleen Heid (Pennsylvania State University), William Jaco (American Mathematical Society), Julie Keener (Central Oregon Community College), Harvey Keynes (University of Minnesota), Glenda Lappan (Michigan State University), Donald R. LaTorre (Clemson University), James Nelson, Jr. (Virginia State University), Peter V. O'Neil (The University of Alabama at Birmingham), Richard Phillips (Michigan State University), Marcia Sward (Mathematical Association of America), Sigrid Wagner (Ohio State University)

I. Report of the Panel

A. Charge to the Panel

The panel met on November 5–6, 1992, in Washington, D.C. It was charged with addressing the question: What is the role of the college and university disciplinary faculty in the mathematical sciences in the preparation of future teachers of science and mathematics? The panel limited its discussion to the preparation of teachers of mathematics, though its members recognized that many of the same conclusions apply to the mathematical preparation of teachers of all scientific disciplines. The panel also limited its discussion to the role of the disciplinary faculty and did not address all of the preparation needed for future math and science teachers or in detail the role of schools of education. Finally, the panel emphasized the undergraduate education of future teachers. Because of the large diversity of backgrounds and interests of members of the panel, it is remarkable that the following recommendations were, except for several points as noted, adopted by consensus of the members.

B. A New Engagement is Needed

Our highly competitive global economy and the increasing complexity of modern society make it imperative that we have a citizenry that is well-educated in mathematics and science. Because of the poor preparation of our present students and because of recent developments that indicate deficiencies in the ways we currently teach science and math, the panel feels that departments in the mathematical sciences need to seek

new ways to engage themselves in the preparation of teachers at all levels, and especially of teachers of grades K through 12. This engagement should take place in partnership with schools of education and with K–12 teachers of mathematics.

The new engagement should involve a rethinking of undergraduate teaching in the mathematical sciences. Those in disciplinary departments and those in schools of education should work together to modify existing and develop new undergraduate mathematics courses that promote in-depth understanding of content and model exemplary instructional techniques. The resulting changes should benefit all students of mathematics, not just prospective teachers.

In addition, mathematical sciences departments should assume responsibility for developing appropriate *mathematics* courses for teachers at all levels. Particular emphasis should be placed on middle school teachers, since the middle school years are a critical and often crucial point in shaping attitudes toward mathematics and in deciding whether students will continue the study of mathematics. Moreover, mathematical scientists, in cooperation with colleges, universities, schools of education, and professional societies, should promote undergraduate programs that result in one-quarter of all future elementary teachers having majors or concentrations in mathematics.

Mathematical sciences departments also have an increasingly important role to play in the *continuing* education of K–12 mathematics teachers. This may be accomplished through summer programs and workshops, or through graduate programs. Mathematical sciences departments need to take responsibility for developing high quality courses and programs that lead to Master's degrees in mathematics or mathematics education and such programs should be developed for teachers at all levels K–12. The mathematics courses should be accessible, appropriate, and relevant to the levels of teachers for whom the programs are targeted. In addition, mathematical sciences departments should be involved in the education of students pursuing Ph.D.'s in mathematics education, whether the degrees are offered in colleges of education or departments of the mathematical sciences.

Mathematical educators have attained a body of scholarly knowledge about teaching and learning that most mathematical scientists have not yet acquired. Mathematical scientists have a responsibility to learn and educate themselves about teaching and learning from the mathematics education community, and in particular from the members of that community who are knowledgeable about curriculum reforms in mathematics education (at all levels).

C. Changes in the Teaching of Mathematics

The panel's conclusions were heavily influenced by the types of conclusions presented in the *Standards* of the National Council of Teachers of Mathematics (NCTM) and in the document *A Call for Change* prepared by the Mathematical Association of America (MAA). Adoption of the panel's recommendations about the teaching of undergraduate mathematics should lead both to more successful undergraduate instruction and to the types of courses that are good exemplars for those students who will go on to teaching.

The panel believes that the learning of mathematics at all levels requires a great deal of active, constructive involvement by the student. This implies that the effective teaching of mathematics at all levels should include methods and approaches that promote active and constructive learning, and in particular this is true in the teaching of undergraduate mathematics. Also, because science is becoming increasingly interdisciplinary and mathematics is becoming increasingly relevant to many of the most important problems of our society, the panel believes that mathematical scientists should take the initiative in breaking down barriers to interdisciplinary activities and connecting students of the mathematical sciences to the uses of mathematics.

At the same time, the panelists recognize that a fundamental and distinguishing characteristic of mathematics is its emphasis on precise reason-

ing and abstraction and that certain "big ideas" in mathematics often illustrate these processes of reasoning and play a role in helping students understand what mathematics is all about. Courses in the mathematical sciences, not courses in mathematics education, are best suited to explain these big ideas. Moreover, innovation in teaching of mathematics should not (and need not) come at the expense of changing the emphasis on these ideas and themes. It should be one of the goals of the new engagement called for in Section B to enable students to develop a broad and unified philosophy of what mathematics is and how one does it. With respect to preservice teachers, mathematical scientists are best able to help them develop a broad vision of the K–16 curriculum, and in particular, an understanding of the big ideas in mathematics that are the foundations for the parts of the curriculum that they will be teaching. Mathematical scientists can set the tone for how K–12 teachers will perceive the goals of mathematics education.

D. How to Bring About Changes in the Teaching of Mathematics

Undergraduate courses in the mathematical sciences can and should be used to educate prospective teachers of mathematics in grades K–12. In addition to their traditional roles, they should model and foster active, constructive learning; should include connections to other disciplines; and should emphasize the relevance of mathematics to the many problems of our society. To make these changes from the current mode of undergraduate instruction will require some curriculum reorganization, education of instructors, and additional resources. Because of their importance in helping to achieve the desired kinds of changes we envision, collaborative and group learning methods and the use of technology should be implemented throughout the undergraduate curriculum. Sample technological tools include graphing calculators, microcomputers in the context of laboratory work, and multimedia presentations. Technology does not have to be very expensive to be effective; however, mathematical sciences departments will need to realign their thinking and attitudes toward collaborative learning and toward enhancement with technology and will have to be equipped with necessary resource materials and technological services to facilitate change and innovation in teaching. The National Science Foundation has a major role to play here. Relevant applications can be brought into all undergraduate courses, and interactions with other disciplines can be coordinated through dialogues with faculty members in other departments and team teaching.

E. Preparation of College Teachers

Making changes in teaching of the kinds we have been describing will require a considerable amount of preservice and inservice education of college teachers. Summer workshops can play an important role in the re-education of the present generation of college teachers and, again, there is an important role for NSF here. Another appropriate role for NSF is to help to fund sabbatical visits by college faculty interested in innovative teaching to institutions that have particularly innovative programs. It will be helpful to have a national program that recognizes "Excellence in Undergraduate Teaching" in departments of the mathematical sciences across the country. The teachers and programs so recognized can then serve as role models, mentors, and examples for others in the mathematical sciences and for prospective teachers.

All graduate students in the mathematical sciences who engage in teaching while in graduate school should be given education in pedagogy, exposure to research ideas on teaching and learning of mathematics, and exposure to innovative methods of teaching, new curriculum materials, technological aids, and national curriculum guidelines such as embodied in the NCTM *Standards* and the MAA *Call for Change*. This education and exposure should involve serious commitment of time, such as in a course or ongoing seminar. Moreover, all graduate students in the mathematical sciences who are

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considering teaching careers at any level should be exposed to these same things, though perhaps not as intensively or as early in their graduate careers as those who actually teach while in graduate school. This is as important for those who would become undergraduate teachers as for those who would become precollege teachers because the former will be helping to educate future precollege teachers. Since learning to teach mathematics involves learning to make clear one's ideas and arguments, all undergraduates majoring in the mathematical sciences would find the same kind of education and exposure beneficial regardless of the career they pursue.

A number of our best new Ph.D.'s in the mathematical sciences should be encouraged to emphasize programs in innovative teaching and to take a serious interest in the teaching and learning of mathematics. The National Science Foundation can play an important role here, by setting up a system of postdoctoral fellowships that would in part be devoted to research as in traditional NSF postdoctoral programs and in part be devoted to developing excellence in teaching. These postdocs could work with some department's recognized "Excellent Teachers," sit in on their courses, and pursue under their guidance some innovative teaching methods and technological aids.

F. Dialogues and Partnerships

In order to begin to make the changes called for in Section B, all departments in the mathematical sciences should develop dialogues on the new engagement called for in that section. The dialogues should start within the department, but should also engage faculty from schools of education, precollege teachers, colleagues from other departments, professional societies, and other outside groups. These dialogues should be made highly visible, through widely circulated written statements, seminars, colloquia, etc. University administrators should be included in these dialogues early on, in order to improve departments' prospects for receiving their support for the changes that need to be made and the resources that might be needed to make these changes. Departments should aim, after appropriate study of such national documents as *Everybody Counts*, NCTM *Standards*, and MAA *Call for Change*, to develop their own position statements concerning appropriate pedagogy for all classes.

The dialogues we are describing should aim not only at making changes in the curriculum and teaching methods within the department, but also at establishing ongoing relations of various forms with the different groups mentioned above. These relations might include, but should not be limited to, visiting teaching positions bringing excellent classroom teachers into mathematical sciences departments or leaves of absence for department members to visit departments that have particularly innovative programs; mathematical sciences departments hiring specialists in mathematics education or encouraging individuals in their department to specialize in mathematics education; or collaborative groups of mathematicians and school of education faculty who would consider research questions related to instructional innovation and student learning outcomes. The dialogues should also aim at leading to ongoing new understandings and procedures, for instance concerning the rewards for those engaged in research on teaching and learning or in the innovative teaching of undergraduates.

It should be noted that, in calling for dialogues to be opened by departments in the mathematical sciences, we should not forget the responsibility of departments of education. Not all of the initiative for these dialogues nor for all of the changes we call for in this report need come from departments of mathematical sciences. Schools of education also have a responsibility, as do other "players," and all groups should seek out each other in the effort to communicate results and ideas about the preparation of teachers.

G. The Required Changes in the Reward System for College and University Faculty in the Mathematical Sciences

Present reward systems in our colleges and universities must be modified to bring about the changes we envision. In particular, research about the teaching and learning of mathematics needs to be recognized as a serious scholarly activity and efforts at developing innovative teaching methods or participation in developing changes in the curriculum or pursuing new partnerships with mathematics educators should be encouraged as being extremely important. A long-term goal would be to have *research* achievements in teaching and learning of mathematics viewed on an equal basis with research achievements in, say, topology or algebra, when it comes to tenure decisions or promotions. This goal, which was favored by all but one member of the panel, will require major changes in attitudes by colleagues and by university administrations. Professional societies in the mathematical sciences have an important role to play here, for example by publishing more scholarly work on the teaching and learning of mathematics in their existing scholarly journals. Most members of the panel believed that such societies should also consider creating new scholarly journals devoted to this topic, while some believed that there are already educational journals for that purpose.

Research in the teaching and learning of mathematics and activities involving innovative teaching, curriculum development, partnerships to promote new teaching methods, and the like should be recognized with prestigious awards from professional societies and funding agencies, and more grants should be made available for the pursuit of such endeavors. Release time should also be made available, through grants and by university administrations, for the pursuit of such activities. These activities should be regarded, indeed applauded, as appropriate for faculty applying for sabbaticals from university departments in the mathematical sciences, as they are for faculty in many non-Ph.D.-granting institutions.

Faculty research in teaching and learning of mathematics and activities related to innovation in teaching of mathematics should, of course, be evaluated appropriately, with such evaluations considering not only the work's interest, importance, and uniqueness, but also the quality and level of its implementation and dissemination.

H. The Role of Assessment

Changes in mathematics teaching cannot be carried out without an accompanying ongoing program of assessment of courses and programs. Mathematical scientists and mathematics educators should work together to create, test, and refine a variety of high-quality new assessment instruments and techniques. Existing courses and programs in the mathematical sciences should be regularly assessed with regard to standards and goals developed by departments and professional societies, and these assessments should lead to plans for program improvement. We refer the reader to the report of the panel on assessment for more details.

I. Diversity

The panel recognizes and applauds the efforts of government agencies, professional societies, and individual departments in the mathematical sciences to achieve diversity, in particular by encouraging more minorities and women to participate in the mathematical sciences. These efforts should be continued. It should also be noted that diversity involves more than just race or gender and includes economic background, geography, and other factors. Reference is made to the report of the panel on diversity for a more detailed discussion.

J. Conclusion

This is an important time for our country. In order for us to function successfully and to

compete effectively in an increasingly complex, highly technological, and globally oriented society, we must make major improvements in our citizenry's abilities, knowledge, and understanding in mathematics and science. Toward this end, we can no longer afford it if our nation's college and university faculties in the mathematical sciences continue to abdicate their responsibility for, and involvement in, the undergraduate education of its future teachers of mathematics. They must assume a more active role in this endeavor and implement major changes in what mathematics is taught and the way in which it is taught.

This panel has carefully considered the role of the college and university disciplinary faculty in the mathematical sciences in the preparation of future teachers of science and mathematics, and has made general recommendations relative to the undergraduate education of future teachers of mathematics. Many of these recommendations are based upon a growing body of research and evidence about how people learn mathematics and should lead to improvements in the education of all of our students of mathematics, not just our future teachers. All of our recommendations are reflective of the strong national movement for change in the teaching and learning of mathematics at the precollege level. The panel does not purport to have all the answers to the many and varied questions that will be raised by its call for a restructuring in the way mathematics is taught to undergraduates. But we have tried to describe ways in which college and university disciplinary faculty can and must have a significant impact. We look forward to the implementation of many of our suggestions.

II. *Reports from Thematic Group Representatives*

A. Instructional Innovation

Donald R. LaTorre, Reporter

The Instructional Innovation Panel met in Washington, D.C., on November 5, 1992, to consider the role of instructional innovation in the undergraduate education of the nation's mathematics and science teachers. Composed of representatives from mathematics, science and engineering, the panel's agenda included presentations, group activities and discussions of ideas, issues, and personal experiences. Although the concern was with the role of instructional innovation in all three of the broad disciplines, this report focuses on those aspects that are of particular interest to the mathematics community.

An overall general consensus of the panel was that the teaching of undergraduate mathematics must change so that it effectively models for future teachers the techniques, ideas, and perspectives that encourage and promote the kind of mathematics learning valued for society in general—learning that enables our students and future citizens to reason and think mathematically and to draw upon mathematical ideas, tools, and techniques to solve real problems.

The panel noted, especially, the spectacular efforts of the National Council of Teachers of Mathematics through the NCTM *Curriculum and Evaluation Standards for School Mathematics* to effect major, substantive changes in school mathematics and how it is taught. And it took equal laudatory vote of the recent recommendations in the Mathematical Association of America's 1991 publication *A Call For Change: Recommendations For the Mathematical Preparation of Teachers of Mathematics.*

In its discussion of the elements present in today's teaching of mathematics at the college level that inhibit the experience of learning mathematics, the panel was quick to identify the prevailing use of the lecture method, reliance on paper-and-pencil techniques, routine template exercises, study in isolation, and narrowly focused tests. These traditional benchmarks of higher education are especially inappropriate for students who would become future teachers because they fail to involve them with the kinds of meaningful experiences with learning mathematics that they will be called upon to provide for their own students: active engagement in constructing their personal understanding through explorations and investigations; the

construction of mathematical models; collaborative work; argument and communication about, and with, mathematics; and the use of technology in meaningful ways. The National Research Council's 1991 publication *Moving Beyond Myths* provides this statement: "Unless college and university mathematicians model through their own teaching effective strategies that engage students in their own learning, school teachers will continue to present mathematics as a dry subject to be learned by imitation and memorization. A similar concern must be expressed regarding the experiences of the graduate students who will become the next generation of college teachers."

In considering instructional innovations that will best encourage and promote new patterns of thinking and new practice in the teaching of mathematics by future teachers, panel members presented and discussed several options: alternatives to the lecture method, collaborative learning, campus e-mail for large lecture sections, effective uses of technology, and laboratory-based learning. This list is not intended to be exhaustive and its elements are certainly not mutually exclusive. Two of the options were cited as offering special promise and high probabilities of success:

- the use of collaborative learning and
- the effective use of current technology, particularly graphics calculators and microcomputers.

Although various models for collaborative learning have been used widely in the teaching of school mathematics, they have not yet been embraced at the college and university level. Collaborative learning refers to any of a variety of activities that involve students, their teachers, and possibly others in learning groups and require the cooperation of the group's members to complete the learning inquiry. The emphasis is on the active participation by students in experiences that facilitate their construction of new understandings and knowledge by linking to previous learning. More than just building bridges between teachers and students, collaborative learning can create a community of inquiry and investigation and help students to confront their misconceptions. Collaborative learning is predicated upon compelling evidence that knowledge and understanding are best created within the student instead of being transferred by the teacher. The several papers presented to the panel on collaborative learning (and that appear as part of these proceedings) provide excellent overviews of both the issues and the opportunities.

More than anything else, the effective use of modern technology gives teachers the opportunity to change how they teach and how students learn mathematics. For technology, especially in the form of calculators and computers, enables us to open up our curriculum to reveal a new richness in terms of interesting problems, their mathematical representation, and strategies for their solution and to open up our methods of instruction by empowering students to explore, to represent, to visualize, and to solve mathematical problems and confront mathematical ideas in new and engaging ways. Graphing calculators are available for use in almost any undergraduate course, and although they may be regarded as inferior to computers in a technical sense, they are not inferior in a pedagogical sense. Indeed, they most often bring a personal dimension to the technological enhancement of learning that is effective in helping students construct their own understandings. College teachers of mathematics must exploit modem technology fully in their teaching of prospective teachers. To do otherwise would be to risk the mathematical development of future generations of citizens who will live and work in a society increasingly dominated by technology.

Finally, the panel expressed special concern over the need for teachers of undergraduate mathematics, particularly in our larger and research-oriented universities, to be encouraged to take the necessary risks and explore innovative pedagogy that could genuinely enhance and revitalize the learning experiences in mathematics of future teachers. Such revitalization could

ultimately change society's attitudes and perspectives on the role and importance of mathematics. This will require major shifts in both attitude and outlook by university mathematicians and administrators and some restructuring of a reward system that mistakenly views research and innovative undergraduate teaching as competitive activities.

B. Valuing Diversity in the Educational Process

James Nelson, Jr., & Richard Phillips, Reporters

Diversity is student heterogeneity, including sex, race, ethnic group, and class; but also student preparation, goals and aspirations, and learning styles; and finally what teachers bring to students, such as their interests, biases, methods of assessing student work, activities, and resources.

Issues of diversity affect the decision processes of these four levels:

Government/Professional Associations
(value diversity)

↓

College Administrators
(include women, minorities, etc.)

↓

Teachers
(utilize learning styles,
effective techniques, activities)

↓ ↓ ↓

Students

Importance of Diversity

Diversity, seen as a resource instead of a problem, helps us come to grips with existing biases and hierarchies.

Diversity of teaching activities in college courses helps students

- gain greater levels of competence
- appreciate diversity as a resource
- gain more tolerance and empathy to deal with the complex issues of our times
- know that all can make a contribution.

Themes and Recommendations

(1) Future teachers should be exposed to a wide range of teaching styles, not only in methods courses, but also in disciplinary courses. There should be considerable emphasis on proactive learning.

(2) Future teachers should have the opportunity to write, interact with each other, formulate their own goals and strategies for dealing with those goals.

(3) Inasmuch as is possible, science and math concepts should be introduced by way of themes tied to diversity issues (gender issues, ecology issues, etc.).

(4) Undergraduate assistantships and internships and mentoring programs all received support.

(5) There was a general view that there should be elements in the training of teachers that emphasize the importance of having a wide range of gender and ethnic groups actively involved in the subject. In support of this goal, there should be special attention paid to not excluding groups by use of exclusive language, attitudes, biases, examinations, etc. We perceive the alienation of minority groups in academia to be a major problem.

(6) The underlying philosophy in the teaching of teachers is that there should be increasing emphasis on concepts and less emphasis on the mechanical aspects of the learning process. This is the desired manner in which they will teach, and there should be elements of this in their own education.

(7) Undergraduate assistantships and internships should be available with duties of tutoring,

directing recitation sessions, and group work, with the existing minority intervention programs in mathematics.

C. Research on Learning and Teaching Science and Mathematics
Sigrid Wagner, Reporter

Research in mathematics education focuses on understanding how students learn mathematics and, by implication, how we can teach individual students better. Much of the early research in mathematics education was conducted by psychologists and used quantitative methods; more recently, the trend has been toward qualitative methods, and mathematics educators have played a major role in conducting research.

When asked their image of educational research, panel members gave a variety of sometimes contradictory descriptions: Highly quantitative social science, not quantitative enough; well intentioned but too scholarly, needs more rigor; jargon-intensive, atomistic (like eating M&M's); theoretically based, informed by cognitive science, sociology, and psychology; irrelevant, practical; dry, exciting; difficult, challenging, a fringe activity with high potential. A contrast was drawn between educational research prior to the 1960's, generally regarded as arcane and relatively useless to classroom teachers, and research of the past 20–25 years, seen as more substantive, practical, and collaborative.

The panel was split into two groups to brainstorm questions that ought to be researched. Some questions of particular pertinence to mathematics included the following:

(1) How can we best teach large lecture sections?
(2) What methods work best for different "kinds" of students?
(3) What techniques get students excited about mathematics?
(4) Do "traditional" teaching methods produce better "math majors" than the methods being encouraged nowadays?

Some issues that emerged are not necessarily researchable but relate more to policy and require thoughtful analysis:

(1) What are our goals in teaching mathematics? Should our goals be different for different students or at different school levels?
(2) In terms of our goals, what advantages or weaknesses do various teaching methods have?
(3) How can we develop and encourage radical new approaches to instruction?
(4) How can we raise standards and expectations without discouraging students?

The need for more sophisticated means of assessment was also discussed, particularly those that would provide more holistic measures of success.

A number of research investigations were described by members of the panel (see papers, this volume) and implications for instruction at the college level were discussed. In closing, some additional musings were raised:

(1) It is ironic that scientists, of all people, seem reluctant to take a scientific approach to issues in education.
(2) To effect significant changes in educational practice, we must change people's beliefs (e.g., about mathematics and how to teach it); how do we change beliefs that are grounded in social conditioning (cf. the lasting influence of street mathematics on methods of problem solving)?
(3) Most schooling is geared primarily toward later schooling, that is, the undergraduate program is designed to meet the expectations of graduate school; success in changing the undergraduate program may depend on changing the expectations of graduate programs.

For further reading on the potential value of research for improving mathematics teaching

and learning, panel members were referred to Ed Silver's chapter in the 1990 NCTM Yearbook cited below.

Reference

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D. Experiences for Elementary and Middle School Teachers

Julie Keener, Reporter

Critical examination of mathematics instruction at the K–12 level has been the focus of the mathematical sciences community for several years. The 1989 publication of the NCTM *Curriculum and Evaluation Standards* and the 1991 publication of the NCTM *Professional Teaching Standards* helped provide a focus for mathematics instruction throughout the United States. These reform efforts at the K–12 levels are having an impact on higher education. With the recognition that how classroom teachers teach is affected by their own educational background, responsibility surrounding improving education is bubbling up to higher education. Also, as K–12 teachers examine questions such as "What is good teaching?" and "How do we measure good teaching?" we realize that these same questions are appropriate for examination beyond grade 12. In 1991, the MAA's Committee On the Mathematical Education of Teachers (COMET) released *A Call For Change: Recommendations For The Mathematical Preparation Of Teachers Of Mathematics. A Call for Change* provides a set of recommendations for the mathematical preparation of teachers from the MAA.

As we examine the "role of science disciplines in the undergraduate education of science and mathematics teachers," it is appropriate and necessary to also examine broader questions concerning appropriate curriculum, instruction, evaluation, and teaching for all undergraduate (and graduate) mathematics and science courses. This is particularly critical as four-year teacher preparation programs become less the norm, making it more difficult to identify the prospective teacher at the undergraduate level. (Many programs are requiring a subject matter Bachelor's degree before pursuing specific education certification.)

As on-going reforms of programs made up of specific courses dealing with specific content takes place, issues surrounding "what mathematics and science are taught" will be the subject of discussion. However, "what is taught" is only one facet of the reform. The NCTM's *Standards* state

> *How* mathematics is taught is just as important as *what* is taught. Students' ability to reason, solve problems, and use mathematics to communicate their ideas will develop only if they actively and frequently engage in these processes. Whether students come to view mathematics as an integrated whole instead of a fragmented collection of arbitrary topics and whether they ultimately come to value mathematics will depend largely on how the subject is taught.

Although this statement deals with mathematics taught at the K–12 levels, the crossover to all sciences at all levels is clear. Changes in instruction can begin in each of our individual classrooms; whether with group projects, utilization of appropriate technology, or material based exploration and development of concepts.

> Ongoing discussions concerning the shape and nature of this mathematics and science reform are currently taking place in many forums at many levels. Documents such as the NCTM *Curriculum and Evaluation Standards*, the NCTM *Professional Teaching Standards*, and the *MAA Call For Change* speak to specific audiences, but their message, recom-

mendations, and vision can provide a platform from which mathematics and science reform in colleges and universities can take place. These discussions and the resulting changes are important, necessary, and energizing.

E. Experiences for Secondary School Teachers

Peter V. O'Neil, Reporter

The day's discussion focused on several aspects of secondary school teacher preparation in the sciences and mathematics. The following is a summary of key points, particularized to the preparation of secondary school teachers of mathematics.

What We Want Teachers To Know and Teach and How They Should Go About Teaching

It is important to form a connection between programs of preparation of teachers of mathematics in secondary school and student learning in these grades. A framework was suggested for knowing whether programs in mathematics give prospective teachers what they need in their classrooms. This framework has four elements:

(1) Development of worthwhile mathematical tasks. This includes topics or activities the class period should be spent on, and issues such as how we judge what a student knows and the kinds of questions a student will ask or think about.
(2) Classroom discourse. This includes how students and teacher communicate about mathematics in a classroom. How do we talk to students about ideas in mathematics?
(3) Building of a classroom environment conducive to learning mathematics.
(4) Analysis. This involves modeling concern about what and how students learn and know about mathematics.

Prospective mathematics teachers need to integrate familiarity with their students with knowledge about mathematics itself and also with pedagogical techniques developed and tested for teaching mathematical concepts.

In some instances there may be demonstrations or experiment-type situations which can be developed to teach mathematical concepts. These might include the use of tiles for learning about areas and the use of various geometrical figures. In an experiment/demonstration setting, teachers must be prepared to encourage students to develop their own ideas about what is happening, attempt to predict later results from previously demonstrated ones, and learn to ask questions which probe the nature of the topic under discussion.

Prospective mathematics teachers should also be involved in research projects in their college mathematics programs. These can be an important factor in giving prospective teachers hands-on experience and confidence with their subject matter. It also develops experience with lines of inquiry, how students approach mathematics, questions that might be generated, and how to present topics to students.

Other factors to be stressed in preparing teachers of mathematics are

- delivering the subject matter,
- handling the tension between breadth and depth of the subject,
- packaging the content,
- coordinating discussion and classroom demonstrations and experiments,
- linking to other disciplines,
- knowing how we know and how knowledge is generated,
- assessing of teacher preparation programs in mathematics.

Use of Technology

Modern technology has produced many instruments of instruction which prospective teachers

of mathematics should be prepared to use. These include hand-held calculators, some of which are programmable. Many of these now have curve sketching capability, and they continue to evolve. For example, some can be connected to demonstration boards to show a class the sequence of a calculation or sketch or to explain how a program might evolve.

Another obvious device which the modern mathematics teacher must be familiar with is the microcomputer. These not only provide an alternative method for tutoring, learning, testing, and assessing, but also provide a means for students to experiment with mathematical concepts. Mathematics teachers must be familiar not only with microcomputers, but with software packages designed for use with students in secondary school.

Computers can also interact with students through relatively new intelligent systems, which employ artificial intelligence to enhance the capability of the program to interact with students, respond to their questions or choices in given situations, and provide feedback directly to the student. There is actually an element of teacher preparation in college classes on such intelligent systems or development of new systems. Some university programs feature courses on these systems and then employ students in subsequent sections to help teach the new students. This provides opportunities for prospective mathematics teachers to learn about intelligent systems and also to experience working with students who are learning about them.

Probably as a result of time constraints, there was no discussion of other technological devices, such as laser disks. These are, however, becoming more popular, particularly in chemistry and biology, and training programs for teachers in mathematics should be aware of this capability and seek ways of using it in mathematics,

Teacher Recruitment

There was a discussion of strategies for recruiting college students into secondary school mathematics teaching. Although there are many external factors influencing such choices, there are also internal factors which can be influenced in recruiting mathematics teachers. These include higher visibility for the profession and developing ways of helping prospective teachers understand and carry out certification procedures. Universities can also help by including preparation of teachers in their reward system for faculty and by scholarship programs aimed at students interested in teaching mathematics at the secondary school level.

Problem Area

One problem is cost. This is apparent in obvious ways, such as introducing computers or other technology into teacher preparation and activities. Less apparent but no less real costs include developing an infrastructure for prospective teachers and incorporating into a traditional teaching/research reward system a component which recognizes and stimulates activity in the preparation of mathematics teachers.

The Role of Physics Faculty in the Undergraduate Education of Science and Mathematics Teachers

Priscilla Laws, Dickinson College, Chair

Panel Members: Robert Beck Clark (Texas A&M University), Frank Collea (California State University, Long Beach), David Hestenes (Arizona State University), Gordon Johnson (Northern Arizona University), Suzanne M. Lea (University of North Carolina at Greensboro), Khin Maung (Hampton University), Jose P. Mestre (University of Massachusetts—Amherst), Duncan McBride (National Science Foundation), David Peak (Union College, Schenectady, New York), Helen R. Quinn (Stanford Linear Accelerator), William Sibley (National Science Foundation), Alvin Siger (Crenshaw High School, Los Angeles), David Sokoloff (University of Oregon), Karen Worth (Education Development Corporation, Newton, Massachusetts)

I. *Report of the Panel*

A. Overview

The purpose of this panel was to suggest actions that should be taken to increase the cultural diversity of students qualified to teach physics in K–12 years. The recommendations of this panel are aimed at physics and education faculty at the nation's colleges and universities as well as toward administrators and funding agencies. Panel members based their recommendations in part on the deliberations of six thematic panels that met earlier in the conference. At least one member of the physics panel sat with each of the thematic groups and reported on outcomes of these deliberations that seemed relevant to the enhancement of undergraduate physics programs for teacher preparation. A brief summary of the key impressions of each reporter is included, while more comprehensive notes submitted by each reporter are appended.

In addition to the reports from representatives of topical panels (Section B), this report consists of a series of recommendations suggested by various Physics Panel members. The recommendations that emerged from the discussions in the Physics Panel fell into three categories: (1) suggestions for new approaches to physics education (Section C), including instructional strategies, curricular design, and the assessment of learning that could strengthen undergraduate teaching for all physics students, especially future teachers; (2) recommendations for actions that should be taken to enhance communication and collaboration (Section D)

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among concerned individuals, organizations, and agencies if teacher preparation in physics is to improve; and (3) a bibliography (Section E) aimed at helping those interested in improving undergraduate programs in physics that affect science teachers. These recommendations are tentative and sometimes contradictory. The deliberations of the panel, lasting only 3.5 hours, was too brief to attempt to reach a consensus on issues. The major goal of the panel was to present current thinking on that matter of teacher education in physics at the undergraduate level that carries with it the collective wisdom of panel members.

B. Key Impressions from Thematic Panels

Members of the physics panel took exception with the adequacy of some of the reports and disagreed with specific elements of others. Thus, comments on the reports made by panel members are included in parentheses as part of these summaries.

Assessment and Evaluation as a Means to Enhance Learning: Methods of assessment have a powerful effect on teaching practices. Some of the assessment panelists believed that the Advanced Placement Examinations which demand factual information and the learning of routine procedures for problem solving are counterproductive. The presence of these tests may be reducing the amount of instructional time spent on conceptual and process goals. It is important to the development of assessments to improve conceptual understanding such as augmenting text problems with more conceptual ones (Jose Mestre), the use of the Force Concept Inventory Examination,[1] and the evaluation of student portfolios (Audrey Champagne).

Instructional Innovation: This panel talked about ideas that are not necessarily new innovations but that are not yet commonly used in undergraduate physics education. These included (1) collaborative activities within lecture, (2) inquiry approaches in the laboratory, and (3) new ways of facilitating student/faculty interactions such as local electronic mail networks. A series of recommendations that apply to physics education were summarized.

Experiences for Prospective Elementary and Middle School Teachers: Panelists called for the development of content courses in mathematics for prospective middle school science teachers that stress active learning, applications, problem solving, and modeling. Prospective science teachers should be exposed to specially designed introductory courses that emphasize the process of doing science more than the coverage of a complete range of topics.

Experiences for Prospective Secondary School Teachers: In physics, background and concept mastery are critically important to the open-ended discovery approach to teaching. Teachers must have depth to teach creatively. The new programs involving thematic integration will make this difficult. Thus, programs aimed at prospective high school teachers should emphasize content mastery, undergraduate research experience, availability of special courses for preservice teachers, recruitment of college students to the program, and enhancement of model instruction, if appropriate, by the use of intelligent tutoring systems.

Valuing Diversity in the Educational Process: This panel believed that NSF should be commended for taking diversity seriously. They identified a need to have the range of diversity of interest be defined and codified. The presence of minority students and teachers are not the only way to increase diversity in the classroom. Other diversities to be considered include the diversity of learning styles as well as of instructional and assessment strategies. Thus, panelists believed that diversity should be viewed as a resource for enriching the educational experience of all students, rather than as a problem, and that the encouragement of diversity is much more than a quest for equity and social justice.

C. Recommendations Regarding Physics Education

Students preparing for careers in teaching at the elementary school level might be well served by

taking specially designed introductory courses as well as courses in methods of science teaching. However, students preparing for careers in middle school and high school teaching will often be taking courses along with physics majors and engineering students preparing for other careers. Thus, it is important that physics departments in the nation's community colleges, four-year colleges, and universities seek continuous improvement of their programs that take advantage of findings in physics education research, materials produced in recent curriculum development projects, new instructional technologies, and new instruments that can be used for the assessment of student learning and course effectiveness. There was consensus on the following learning principles based on the outcomes of research in physics education[2]:

1. The ability to solve standard problems is inadequate for functional understanding of physics. Questions that require qualitative reasoning are essential.
2. Most students are unable to develop a coherent mental framework for understanding physics phenomena on their own. They need help and encouragement in this task.
3. Certain conceptual difficulties must be addressed in more than one context. Significant conceptual change requires *repeated* challenges.
4. Connections among concepts, formal mathematical and graphical representations of these concepts, and the real world are not made by most students.
5. Teaching by telling is ineffective.

New assessment tools that can be used for introductory courses are now available for topics in mechanics,[2] heat and temperature,[3] and circuits[4] that test for the compatibility among curricula, instructional techniques, and learning goals. Careful diagnoses of these tests are a powerful means by which undergraduate instructors can assess their courses and the progress of individual students.

Many physics faculty members are unaware of new developments in educational research, curriculum design, and instructional technology. The widespread dissemination of these new developments is of critical importance. Ways to encourage physics faculty and college and university administrators to place more value on teacher preparation must be sought.

Faculty interested in participating in the development of teacher preparation programs should be given opportunities for career advancement, acquisition of instructional space and apparatus, project stipends, and attending conferences. Departments should seek to set up model programs and reward those who participate. Thus the physics panel had the following recommendations:

1. *Recommendations for Individual Departments*

- Physics departments should seek continuous improvement and review of curricular offerings in light of new developments in physics education and support physics education research efforts. This includes the articulation of overall learning goals for students in the program and goals for specific courses within the program and the design of curriculum and assessment tools to measure the success of the program (see below).
- In terms of career advancement and working conditions, departments should support and reward faculty who teach and develop curricula for teacher preparation programs in the same way they support those who conduct research and upper-level teaching in physics.
- Undergraduate physics departments should broaden the outreach of their highly mathematical major programs to encompass students preparing to teach or pursue other career options which do not require graduate work in physics.
- The continued development and testing of assessment tools should be promoted and faculty should use these tools to diagnose

their teaching and identify the learning problems of individual students.

- Administrators and faculty members who have not had significant exposure to new developments in physics education should read at least the materials listed in the short bibliography at the end of this report.
- Departments should assign a senior-level faculty member on a full-time basis as an introductory physics curriculum developer. The developer's duties should include the task of overseeing the continuous review and improvement of the introductory physics curriculum and teaching environment over and above the traditional coordination functions.
- The training of graduate and undergraduate teaching assistants to use some of the new principles of effective teaching should receive high priority. This should be one of the primary responsibilities of the introductory course curriculum developer.
- Departments should develop recruitment programs to interest capable students in preparing for careers in K–12 teaching.

2. *Recommendations for National Activities*

- New developments in physics education should be reported in widely read publications in the form of articles as well as in editorial and news reports on a regular basis. These publications include *The American Journal of Physics, The Physics Teacher, Physics Today, The Two-Year-College* Newsletter, and *The APS Forum on Education* Newsletter.
- One of the professional organizations such as the American Association of Physics Teachers or the American Physical Society should seek funding to send consultant teams to help institutions enhance their physics programs in light of current developments in physics education with special attention to the preparation of future teachers at the K–12 level within the context of the undergraduate physics program as a whole.
- A resource letter in physics education should be prepared and published in the *American Journal of Physics* as soon as possible.
- A national teleconference in undergraduate physics education similar to one held recently in mathematics using NSF funds should be organized for 1994.
- A funded electronic mail network for those interested in physics education should be formed. A network coordinator/moderator should receive funding to keep the level of discourse high and meaningful.
- The American Physics Society Forum for Education on K–12 should be encouraged to continue its plans to keep the research community at divisional meetings informed of new developments in physics education.
- More NSF-sponsored chautauqua short courses on physics education and teacher preparation topics should be offered.
- Continuous efforts should be made to assess the educational potential of new technologies such as microcomputer-based laboratory systems, video analysis tools, modeling software, symbolic manipulators, hypermedia, intelligent tutors, and interactive CD-ROM.
- Workshops, seminars, and conferences should be organized on the topic of curriculum development for preservice teacher courses in physics, mathematics, and the physical sciences. Professional societies such as the American Association of Physics Teachers and the American Physical Society should be encouraged to organize sessions and workshops at national and regional meetings. Institutions and organizations should solicit curriculum development funds and funds for conferences, workshops, and seminars from Federal agencies and private foundations.
- Both Federal agencies and private foundations should be encouraged to expand and design new, more effective funding programs to enhance teacher training efforts.

- National groups such as the National Science Teachers Association, the Holmes Group, National Council for the Accreditation of Teacher Education, and the American Association of Physics Teachers should cooperate in the development of new national recommendations for teacher certification in physics that are appropriate in scope and content. There is a debilitating lack of uniformity in standards.
- Since minority participation and that of female students is more of a problem in physics than in any other science discipline, special emphasis should be placed on K–12 curriculum development projects and teacher preparation curricula that are culturally sensitive and pay special attention to the needs of these students.

D. Communication and Collaboration

In recent years there has been little communication between departments of physics and departments of education at many institutions. Ways must be sought to enhance mutual respect among physics departments and the education departments through means such as cooperative teaching.

In addition, collaboration among university teachers in science and education with those teaching in grades K–12 could serve to revitalize science curricula in the nation's schools. Recommendations of the panel include

- Seek ways to attract leading research scientists in industry and at leading research universities to participate in the development of K–12 curricula in science and mathematics. Glen Seaborg, Leon Lederman, Ken Wilson, and Philip Morrison are examples of scientists who have committed themselves to education.
- Provide programs in which undergraduate teachers can gain experience working with K–12 teachers and students.
- Encourage interdisciplinary team teaching and curriculum development in physics, mathematics, and allied sciences.
- Develop a system in the NSF research proposal process which provides incentives for applications to plan presentations of their proposed research to teacher and student groups at the K–12 levels.
- Develop a program in which scientists working for Federal agencies and laboratories would give presentations of their research to teacher and student groups at the K–12 levels.
- Provide funding for conferences and workshops in which members of two or more organizations can share ideas on teacher preparation.
- Encourage the submission of curriculum development proposals in which the Principal Investigators represent different departments or organizations.

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2. McDermott, L.C. July 1992. "How we teach and how students learn." Presented at Teaching Modern Physics: Statistical Physics, Badajoz, Spain.
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ment of Physics, University of Oregon, Eugene, OR 97403; 503/346–4755.

II. Reports from Thematic Group Representatives

A. Instructional Innovation

Helen R. Quinn, Reporter

New or innovative approaches desirable in college teaching were described as follows:

- collaborative or interactive learning interspersed in lectures, even with large classes.
- open-ended problems and inquiry-based approach in lab and small-group settings.
- interactions of students with faculty facilitated by a variety of approaches, network "office hours" as one successful example.

These approaches improve learning for all students but are especially important for prospective teachers because

- they stimulate interest in scientific inquiry
- they stimulate a pattern of lasting curiosity that encourages continuing learning.
- they reinforce for teachers the view that this is the way to teach science and will thus affect the subsequent teaching style of these teachers.

There is need for further support and reinforcement for teachers to be able to implement these approaches in their schools:

- classroom space and class size must be appropriate for group work.
- teachers need sufficient allowance for preparation and set-up time.
- teachers need sufficient funding for materials for activities.
- school atmosphere and administration must be supportive of "lively" classrooms.
- ongoing inservice opportunities to advance teachers' subject knowledge and expose them to the best available curriculum materials and equipment are essential.

Needs at colleges and universities to promote innovative teaching were considered by panelists:

- reward structure that recognizes time spent on instructional improvements.
- a network for college teachers to share ideas and approaches that work.
- teamwork between education and discipline departments, e.g., team-teaching of science education courses.
- NSF role to provide incentives that pressure universities to move in these directions, most funding initially to those institutions that produce the most teachers.

Other components of the process include the following list:

- involvement of discipline experts, working with teachers to develop appropriate and scientifically correct curriculum modules.
- evaluation criteria for state adoption need to evolve to reflect new types of curriculum materials
- ongoing partnerships between colleges and local schools involving college faculty in workshops, equipment loans, or demonstrations and networking interactions with teachers.

B. Valuing Diversity in the Educational Process

Alvin Siger, Reporter
(based on notes by Craig E. Nelson)

1. Commend NSF for taking diversity ever more seriously.
2. Diversity and student heterogeneity generally; general aspects of student diversity: preparation, goals and aspirations, learning styles, personal features, and history.

3. Diversity considered as a resource, not a problem. Corollary: Need to come to grips with exploring existing biases and hierarchies.
4. Centrality of employing a diversity of teaching activity in college science courses:

   - Diverse ways of learning and excelling; success for all and development of a sense of competence.
   - Provides a repertoire of teaching and assessment strategies.
   - Helps students appreciate diversity as a resource.
   - Let student experience teaching (to consider).
   - Modeling by college faculty may include both using approaches that can be adapted by teachers and using others that are appropriate for adult learners but may not be as appropriate for preadults.

5. One of the most important strategies to utilize and model is the development of student learning communities:

   - Foster greater levels of achievement.
   - Faculty need to set up community so that they strive for excellence rather than settle for mediocrity.

6. Need to set traditional content into larger contexts that focus on major theories, critical thinking, valuing, and social connections to students' lives.
7. Need to involve subject-matter-specific faculty more deeply in explicitly subject-matter-specific teacher training.

   - Sharing of powerful demonstrations and activities.
   - Plug into professional-disciplinary-based networks.
   - Planning of teaching: major themes, diversity of activities, utilizing student diversity.

C. Assessment and Evaluation as a Means to Enhance Learning

David Hestenes, Reporter

There is general agreement among teachers and educational researchers that methods of assessment have a powerful effect on the conduct of high school science courses. In particular, standardized tests, such as the Advanced Placement Exam, are perceived as demanding factual information, and many teachers as well as students believe that the most effective way to prepare for these tests is rote drill, and practice panelists discussed several different kinds of test which promote deeper conceptual learning strategies.

Two of the panelists are physicists. Jose Mestre, the Panel Chair, suggested augmenting standard physics problems with the requirement that students describe the strategy they use to solve them, and he presented some empirical evidence that this improves their understanding. David Hestenes discussed the *Force Concept Inventory*, a test designed to detect student misconceptions about mechanics. This test and its implications have been thoroughly discussed in *The Physics Teacher* (March 1992). One implication of the research reported that problem-solving instruction cannot be effective unless and until basic misconceptions have been adequately addressed.

Audrey Champagne demonstrated the value of open-ended groups assessment tasks. Participants were delighted to see how much their individual responses to given tasks were enriched by discussing them in small groups of their peers. This kind of activity also occurs in physics classes, but not often enough and seldom with so careful a design.

Angelo Collins (1992. *Sci. Ed.* 76, 451–463) discussed the use of portfolios in learning and assessment. A *portfolio* is defined as a container of documents which constitutes evidence. Therefore assembly of a portfolio requires clear articulation of a thesis or point-of-view and construction of an argument to support it. This

task provokes rich and ingenious responses from students. The only thing like it in conventional physics instruction is a lab report, but students seldom respond to lab reports with such delight! The lab experience could probably be enriched by incorporating some ideas from the "portfolio literature."

D. Experiences for Elementary and Middle School Teachers

Gordon Johnson, Reporter

Charge: What kind of science and mathematics experiences should preservice elementary and middle school teachers have?

The participants agreed that there should be differences in the extent and amount of science and mathematics experiences but that the experiences should have similar characteristics. Preparation for the middle-level teacher requires great breadth—possibly in both science and mathematics. Content area studies need to recognize that the middle level teacher of science or mathematics has the role of a specialist in these areas.

Group members recommended that special content courses in mathematics be provided for preservice teachers. These courses would employ active learning approaches and stress applications, problem solving, and modeling. Courses would be staffed by people trained in mathematics education.

Introductory science courses should be designed with characteristics in mind that are important for preservice teachers. Those same characteristics, however, would benefit all students enrolled in introductory science courses. The identifying characteristics include experiences that involve investigation, student discovery, problem solving, how knowledge comes about in science, taking wrong turns, making and recognizing mistakes, and other aspects related to the nature of science. The group recognizes that not everything can be done in an introductory course and that including the above priorities may preclude as much content coverage. Courses need to take into account the differences in maturity of thinking and in learning styles of students populating the course.

Group members agreed that the characteristics identified above could be accommodated in separate single discipline courses, in multidiscipline courses, or in some combination of discipline and integrated courses. Specific recommendations related to the depth versus breadth controversy and to content covered in these courses were unresolved in the time devoted to this discussion. Some suggestions about content included that specifics might be determined by the problems investigated and by student concerns and interests. The students' "need to know" and the importance of engaging and involving the student seemed critical factors in determining specific content.

1. Facilitating Proposed Changes in the Introductory Science Courses

Several strategies were proposed to assist the implementation of these changes. Included were the following:

1. Use the laboratory as a first step in promoting change.
2. Capitalize on administrative support whenever it is available.
3. Volunteer to teach the introductory class and test the proposed changes.
4. Make use of the professional organizations in the content areas.
5. Use assessment techniques now being advocated to measure desired outcomes of instruction. (Make use of resources in college of Education and AAAS publications.)
6. Gain familiarity with current learning theory and available technology for assisting learning.
7. Make use of existing reward structures and expand them if necessary to include curriculum development, learning research, and funding.

2. *Suggestions to NSF to encourage implementation:*

1. Support pilot projects.
2. Support curriculum development that includes faculty development for training in instruction and assessment.
3. Support research and development in the teaching and learning of science.

E. Experiences for Secondary School Teachers
Robert Beck Clark, Reporter

Of the many topics discussed during the Experiences for Secondary School Teacher Thematic Working Group, there were six which I thought would be of particular interest to physics teachers:

1. The critical importance of mastery of physics content in the preparation of physics teachers. In particular, it was believed that content mastery is particularly critical in providing teachers with the confidence necessary to teach using an interactive discourse method in their teaching. It was also stressed that content knowledge is specifically empowering for science to be taught as science and not only as natural history.
2. Opportunities for prospective teachers to participate in the practice of science by personally engaging in research were considered to be of special value.
3. An interesting model for giving special attention to prospective science teachers in a setting utilizing large lecture sections for introductory courses is the creation of special recitation and laboratory sections for prospective teachers and was reported from the Project 30 program at the University of Georgia.
4. A program for the recruitment of prospective physics teachers at Texas A&M University was reported and might be considered as a model for physics teacher recruitment on university campuses throughout the United States. This is particularly critical in view of the continuing shortage of qualified physics teachers in much of the nation.
5. The future potential of Intelligent Tutoring Systems in the preparation of prospective physics teachers and a particularly interesting program developed at the University of Massachusetts was described and discussed.
6. Last, but definitely not least, is the critical importance of model instruction by physics professors in undergraduate physics courses taken by prospective physics teachers. Continual efforts to improve the quality of undergraduate instruction are essential.

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Supplement: Participants in the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers

November 4-6, 1992

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NATIONAL SCIENCE FOUNDATION SUPPORT FOR PREPARATION OF TEACHERS

Precollege mathematics, science and technology education is facing exciting demands and challenges. The increasingly complex subject matter and level of understanding required of all citizens challenge teachers to be current with changes in discipline content and methods of instruction. The increasingly diverse student body challenges teachers to design classes that build on diverse backgrounds and needs. Advances in teaching technologies and assessment methods challenge teachers to incorporate these new developments into their daily classroom activities. Since the content and teaching of K-12 mathematics, science and technology must undergo substantial change, the training of precollege teachers must also change. Departments, faculty and current teachers involved in the reform effort must be afforded the necessary time and appropriate recognition for their activities. In addition, adequate scholarship support is needed to encourage outstanding students to enter and complete these new, more demanding pre-service teacher programs.

Realizing the importance of undergraduate education in adequately preparing to meet the increasing challenges of science, mathematics and technical education the NSF Division of Undergraduate Education has designed two mechanisms for submitting proposals regarding teacher preparation. Those proposals submitted from several departments or a consortium of institutions, which seek to effect major redesign of current teacher preparation programs, should be submitted under the **Collaboratives for Excellence in Teacher Preparation** program. In addition, Teacher Preparation proposals are encouraged in other DUE programs as appropriate: Instrumentation and Laboratory Improvement (ILI), Course and Curriculum Development (CCD), and Undergraduate Faculty Enhancement (UFE).

Collaboratives for Excellence in Teacher Preparation

The principal aim of the Collaboratives for Excellence in Teacher Preparation program is to encourage education, science and mathematics faculty to collaborate on the design and implementation of teacher preparation programs that will produce K-12 teachers who are excited about incorporating mathematics and science into their daily classroom activities, knowledgeable in the subject matter, confident in their abilities within the disciplines, and creative about designing engaging and informative science and mathematics activities for a diverse population of students. The program expects to fund several Collaboratives for Excellence in Teacher Preparation in amounts from $500,000 to $1,000,000 per year for up to five years.

Teacher Preparation Supported Through All Undergraduate Education Programs

Proposals that improve the mathematics and science preparation of prospective teachers are encouraged in all NSF Undergraduate Education programs. Supported projects under these programs are typically of a smaller scale than those supported through the Collaboratives. They include laboratories providing hands-on experience for prospective teachers (ILI), the development of undergraduate courses and curriculum designed to take into account the needs of prospective teachers (CCD), and short courses and workshops that enable college mathematics and science faculty to meet the needs of prospective teachers (UFE).

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